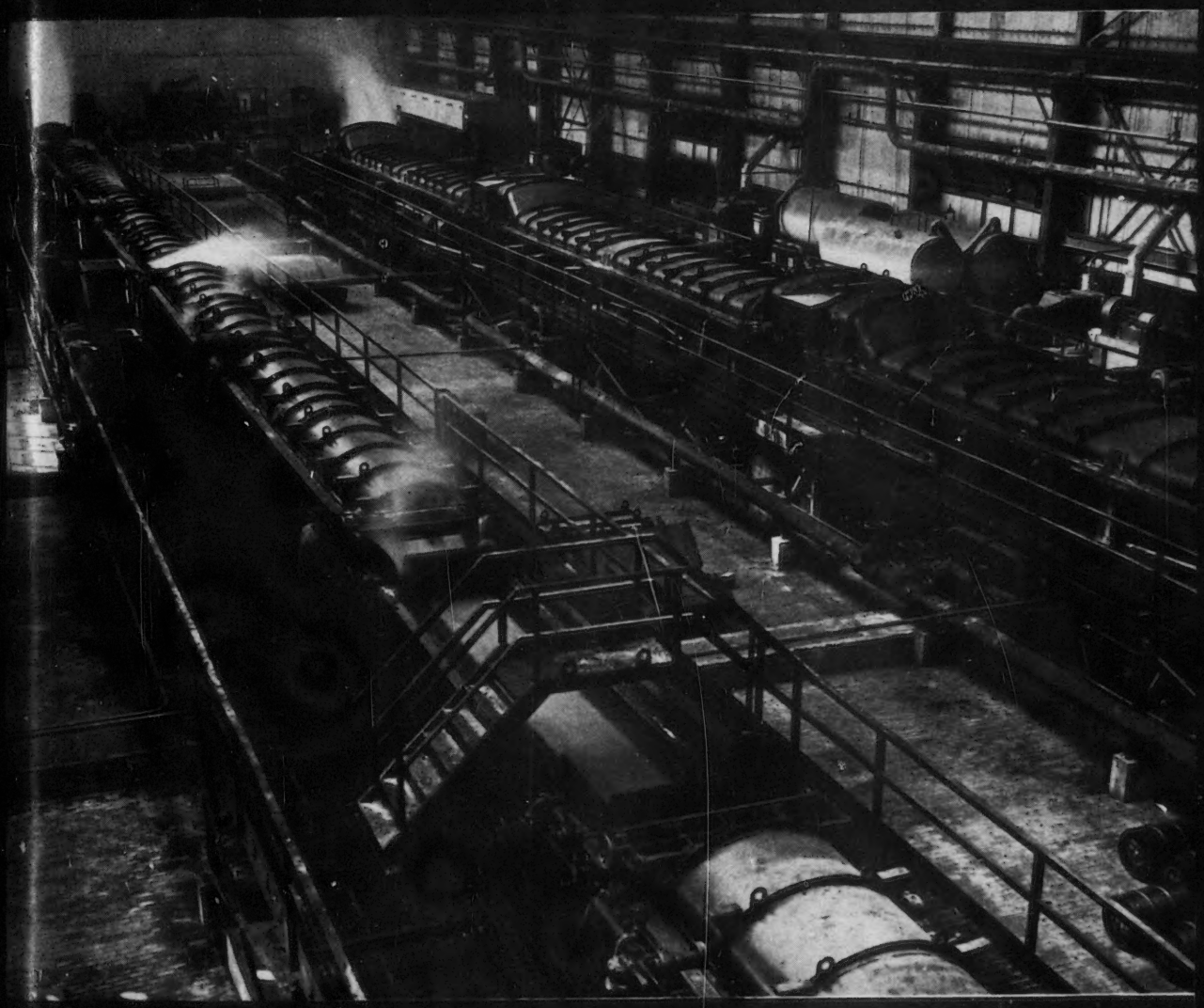
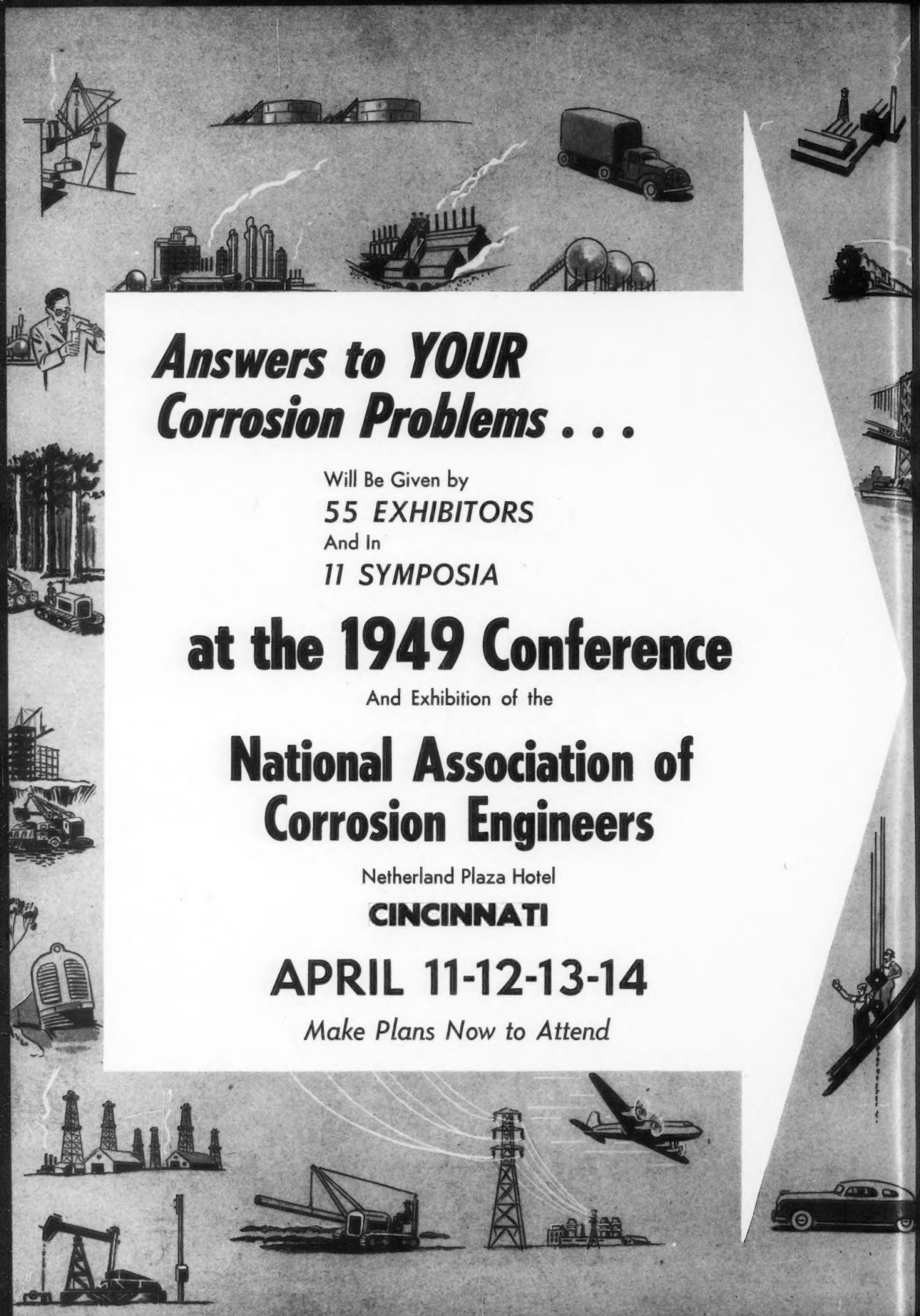
Corrosion





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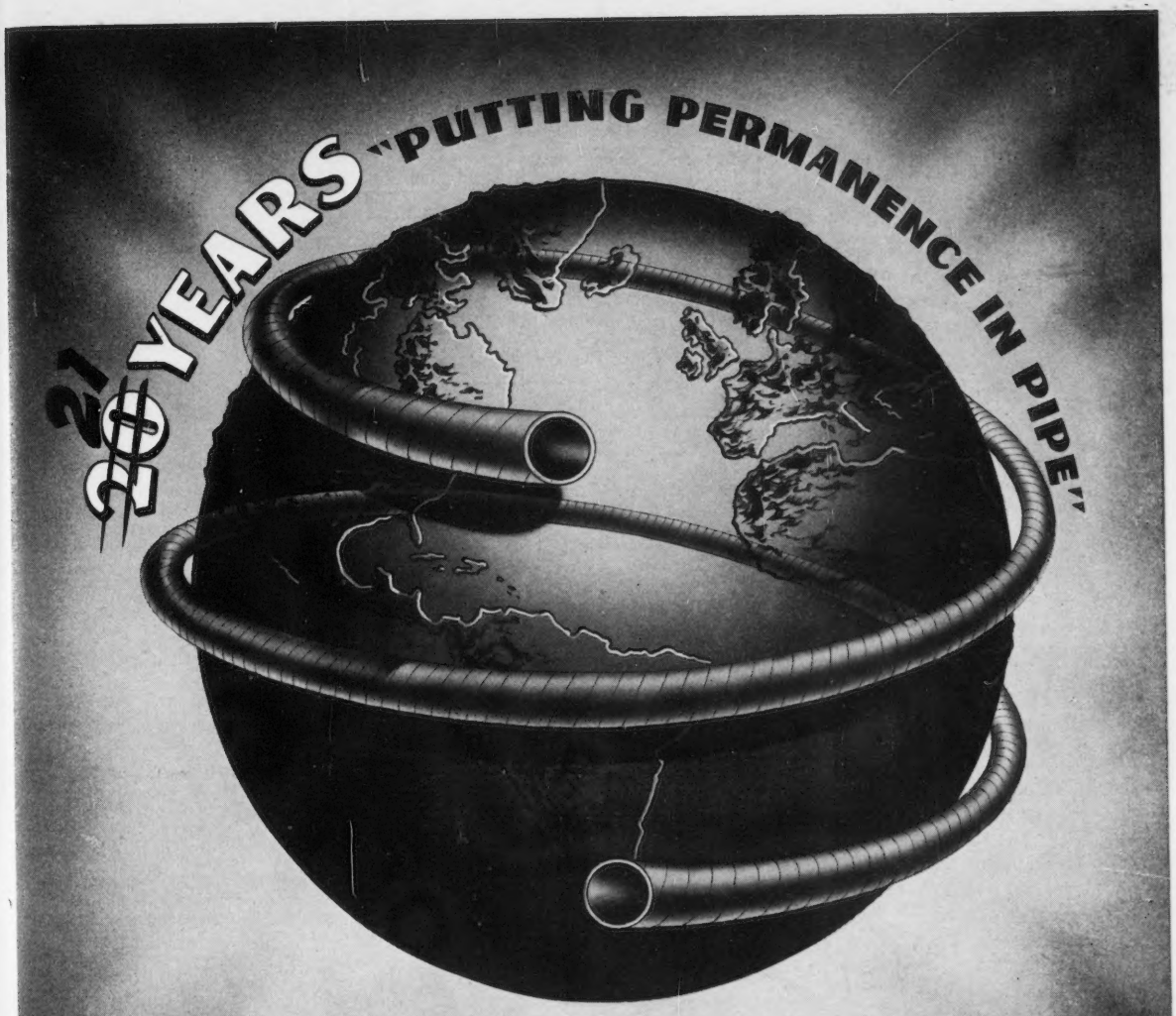

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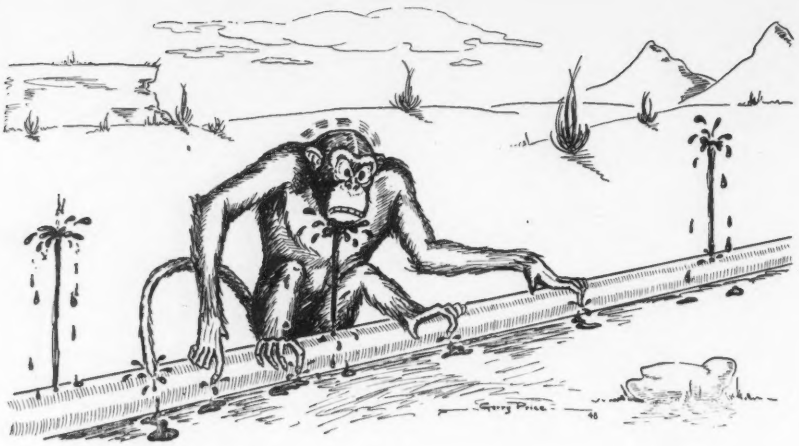

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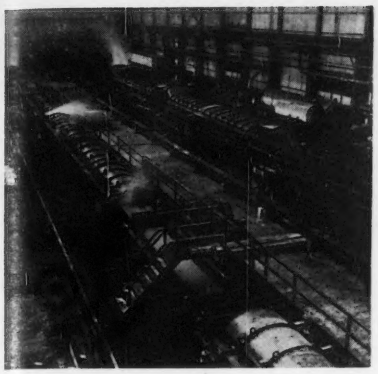

Continuous pickling lines in the Irvin Works of Carnegie-Illinois Steel Corp. are shown here. Hot rolled and semi-finished steel passes through four acid tanks for the removal of scale and oxides preparatory to cold rolling. Automatic machinery unrolls strips and joins them so that work passes through almost continuously.

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Corrosion

devoted entirely to

CORROSION
Research and Control

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Vol. 5 **JANUARY, 1949** **No. 1**

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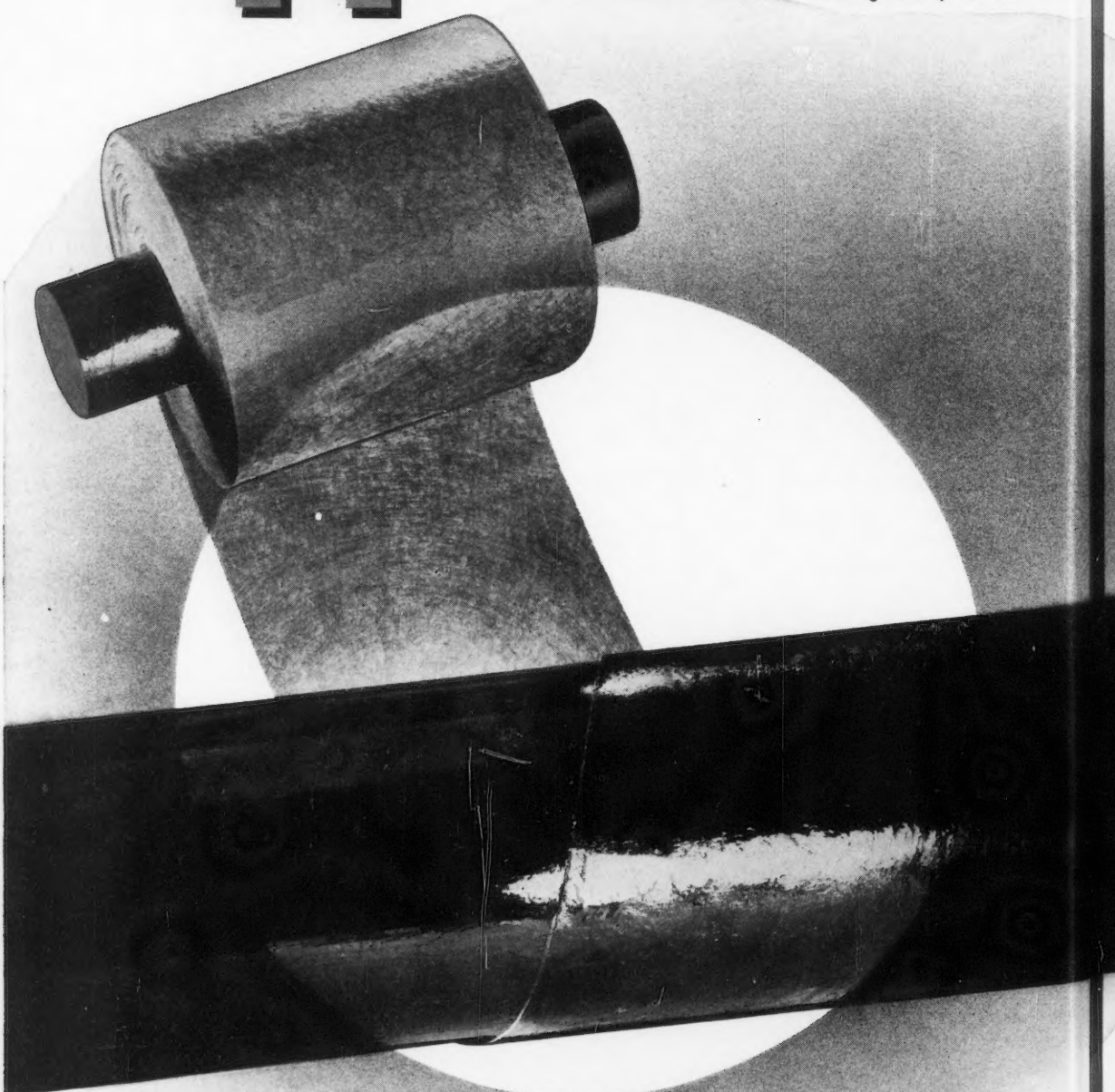

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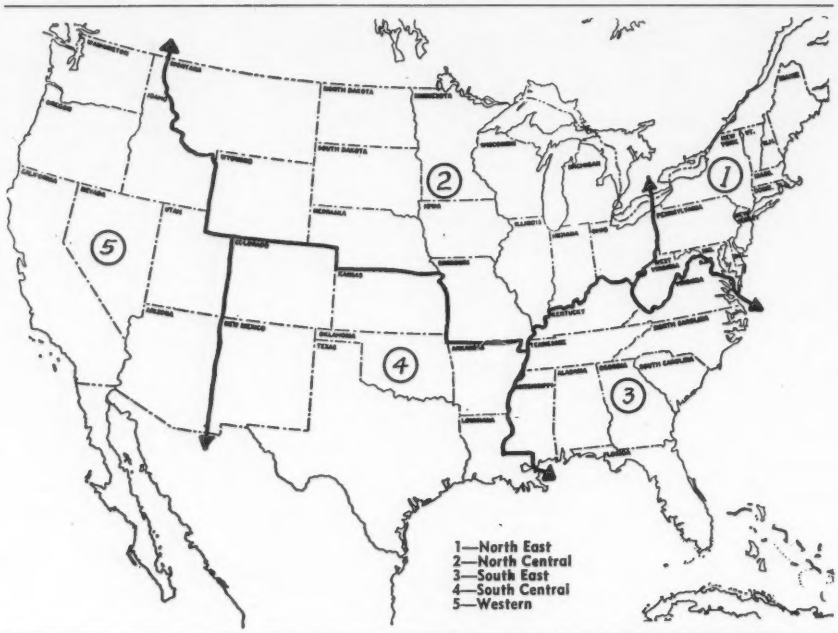

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Engineering Facts about

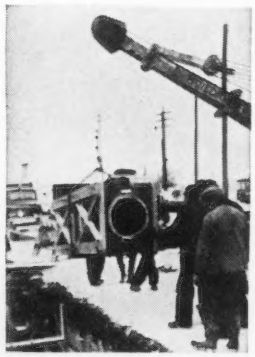
Johns-Manville TRANSITE PRESSURE PIPE

*Winnipeg: A case history**

IN 1932 the city of Winnipeg, Manitoba, made its initial installation of Transite Pressure Pipe. A portion of the installation consisted of an 18″ line. Recently this pipe was subjected to a series of field and laboratory tests to determine its condition after 14 years of service, which had included exposure to an extremely corrosive soil.

Pitometer Flow Test

Before the pipe was removed from the line for the laboratory tests which were to follow, its flow capacity was checked. The Pitometer Company, Inc., New York, was selected to conduct these field tests. Velocities ranged from 1.1 to 1.9 feet per second and readings were made at 30-second intervals. During each test, the velocity was held constant. Results were summarized by the Pitometer Company as follows:



Assembly of pipe and coupling being removed from the line for laboratory tests.

"The high value of C-140, which we believe is a reliable index of the present capacity of the pipe tested, shows that there has been little if any loss in capacity since 1932 when the pipe was laid."

Readings being recorded during Pitometer flow tests on the line.

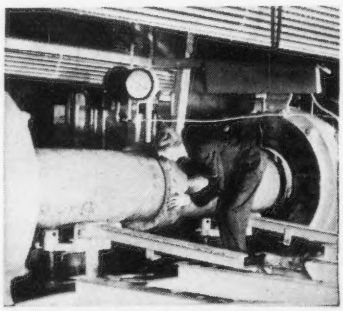
Soil Conditions

The soil in which this Transite installation was made was known to be destructive to water pipe. Analysis showed the presence of certain soluble salts, which, when dissolved by ground water, became highly corrosive.

It was desired, therefore, to determine how well the Transite line had withstood these severely corrosive conditions and thereby to provide a basis for gauging its life expectancy. To do this, a series of physical tests were made, using the sections of pipe which had been removed from the line for the purpose. The most significant of the tests conducted on the pipe were the hydrostatic pressure tests.

Hydrostatic Pressure Tests

In order to simulate field conditions as closely as possible, an assembly consisting of portions of two lengths of pipe joined by a Simplex Coupling with rubber rings and sleeve intact was tested. The complete assembly was placed in a hydrostatic testing machine and the water pressure was raised to 260 pounds per square inch. This was the original test pressure to which this pipe had been subjected at the factory and 4 times the normal working pressure of the line.



Assembly of pipe and coupling undergoing hydrostatic pressure test.

Pressure was held at 260 pounds while observers closely examined the coupling for leakage. No leakage occurred. The rubber rings, undisturbed and in their original position, functioned as well as when the pipe had been placed in service 14 years previously. Subsequent careful inspection and tests confirmed that the rubber rings removed from this Transite line were free from any signs of deterioration.

Specimens of the Winnipeg pipe were also subjected to other laboratory tests. Crushing tests showed that its strength compared favorably with that of Transite Pressure Pipe as manufactured today. A corporation stop pull-out test provided further verification that the strength of this pipe was in no way impaired.

Summary

The above series of tests provided conclusive evidence that the strength, flow capacity and other physical characteristics of the Winnipeg pipe were unimpaired after 14 years' service under severe conditions. Further, as summarized in the original report, they demonstrated that "on the basis of the performance rendered to date, it is reasonable to anticipate a life-expectancy of many times that already obtained."

* *A copy of the detailed performance report on this Transite Pipe installation is available on request. Address Johns-Manville, Box 290, New York 16, N. Y.*

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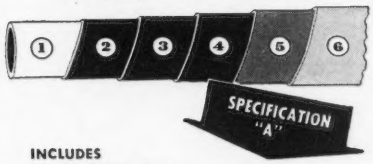

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(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) One spiral wrapping of heavy kraft paper.

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(1) Mechanical cleaning.
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(3) Hot application of desired coating.
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(5) One spiral wrapping of desired wrapping material.
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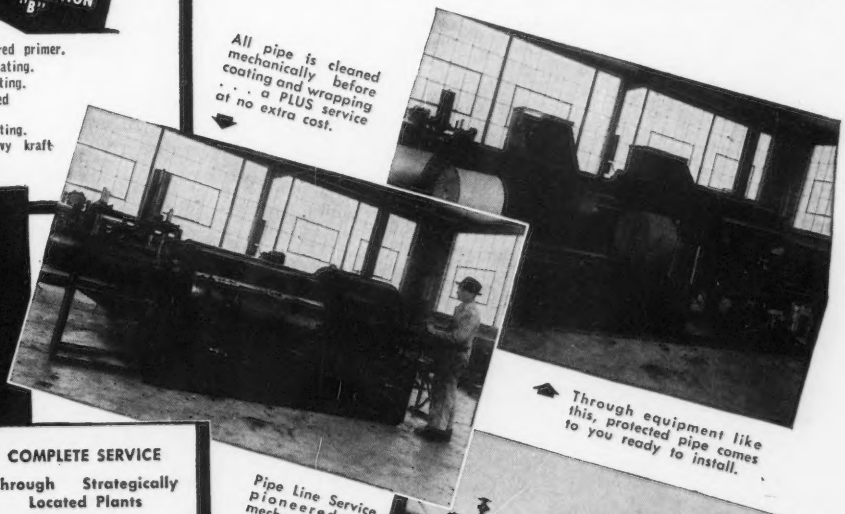

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the beautiful Skeletons in milady's closet

During the last generation or so a mighty textile industry has developed from tiny skeletons. It is the rayon industry, and the skeletons are from vegetable cells. From a humble beginning in 1911, production of rayon in the United States has grown until it reached nearly a billion pounds in 1947.

Rayon is made by three methods in this country, but all of them are based on cellulose as the raw material. In fact, viscose rayon, which supplies nearly three-fourths of total production, is nothing but cellulose that has been put through the mill and finally regenerated. And cellulose is nothing more than the carbohydrate skeletons of vegetable cells — it is the essential and characteristic substance of the entire plant world, which chemical industry has turned into a beautiful new textile for the human family.

Viscose rayon may begin and end with cellulose, but many complicated chemical and mechanical steps intervene before the large molecules of pulp can be converted into the smaller molecules of pure cellulose that make up the finished filament. Briefly, the pulp must first be treated with caustic, shredded, aged, "xanthated" with carbon disulfide, dissolved, ripened, filtered and freed from air. The solution is then spun in an acid bath, the filaments combined into yarn, purified, bleached, washed, oiled and dried. Enormous technical difficulties needed to be overcome before this process became a commercial success.

RAYON MUST BE PURE

Many of these steps require the use of strong reagents that are corrosive to ordinary materials of construction. For instance, viscose rayon is the chief consumer of high-grade caustic soda. Yet one of the absolutely indispensable conditions of success in viscose manufacture is freedom from the metallic impurities which are known to interfere. For this reason the utmost care is commonly taken by rayon-producers to lessen the danger of contamination by corrosion products.

In the course of time, INCO's Corrosion Engineering Section has "sat-in" on many problems of rayon production as they are affected by the need for resistant equipment. Our staff will be glad to place this fund of experience at the disposal of anyone who feels that corrosion is one of the headaches he had to contend with. There is no obligation. Just send for a copy of the Corrosion Data Work Sheet, which is designed to clarify the essential technical factors that need to be considered.

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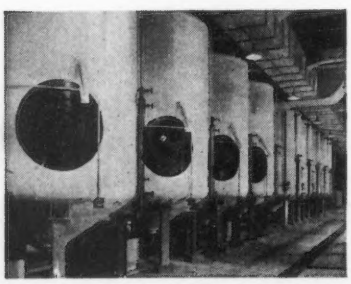

There are 38 of these large viscose aging-tanks in the plant of one of the largest rayon-producers in the United States. They are approximately 8' in diameter and about twice as high. For more than 10 years these tanks have served to protect viscose solutions from contamination by impurities that would exert a deleterious effect on the process. They are constructed of Lukens Nickel-Clad Steel and supplied with fittings of solid nickel. The fabricators were **Hedges-Walsh-Weidner Division of Combustion Engineering Corporation; Alloy Fabricators, Inc.; Babcock and Wilcox Co.; and Blaw-Knox Co.**

A Message from Your Officers

This Month's Contributor

L. J. GORMAN, *Director, Representing Active Membership*

WITH this new issue of Corrosion, your Association enters the New Year with a wish for the happiness and prosperity of all its members and their families everywhere. To this greeting, it is desired to add one or two observations relative to the progress and growth of the association.

In the relatively short period of five years, the progress made by our association, in growth and achievement, has been outstanding. The active and junior membership has passed 1600. The associate and corporate membership is approaching 250. Although the membership in each category is rapidly increasing, we must not relax on the matter of membership. The potential membership for NACE is many times the present enrollment. Membership is the responsibility of each member of the association.

Corrosion represents a loss in our national economy which is enormous. The annual costs are variously estimated in billions of dollars. When the hazards incidental to structures weakened by corrosion are added to the costs, the problem presented is a challenge to the best there is in research and engineering. This Billion Dollar project in the conservation of metals, so essential to our national life, is the responsibility of the corrosion engineer. Consequently, the organization and planning for NACE must be on a scale comparable with the magnitude and scope of its assignment.

Corrosion control presents a wide variety of projects in which the development of the technical knowledge underlying the principles of corrosion, and the practical application of these principles, require the close cooperation of the research specialists and the field engineers working together in technical committees. Several of these committees are now at work on projects that call for top grade research and engineering. Since the ultimate beneficiaries are the associate and corporate members supporting our association, it is important that this committee work be expanded and pursued with a view to the formulation of certain principles and practices which can be recommended to industry as guides to the mitigation of corrosion.

For effective results, information relating to corrosion control must be disseminated throughout all phases of industry, wherever metals are used. This can be accomplished, most effectively, through the expansion of NACE membership, and the organization of local sections in every industrial community wherever ten or more members can be assembled. This organization, which is being coordinated in the regional areas by the regional divisions, is well under way in many of the larger communities. Its extension to the smaller communities is equally important. Relative to this, it is desired to emphasize the importance of the missionary as well as the technical work to be accomplished by NACE through its local section organization.

Moreover, as the association grows, the local section becomes increasingly important in providing for the personal contacts, the discussions, and the opportunities for active participation in the association by its younger members. These local activities constitute the life-blood so essential to the health and growth of our association.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) to promote scientific research in determining the causes of corrosion and methods of its control with respect to theory and practice.

(b) to provide a means of exchange of knowledge and ideas among those individuals actively engaged in the control of corrosion.

(c) to promote methods of control of corrosion.

(d) to promote standardization of terminology, methods, equipment and design in the development of methods of corrosion control.

(e) to foster cooperation between individual owners of metallic structures in the solution of their joint corrosion problems.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers are nominated by (1) the Board of Directors, or (2) a quorum of at least 25 members, and elected by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 905 Southern Standard Building, 711 Main Street, Houston 2, Texas.

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Sun Oil Corp., Philadelphia, Pa.

F. L. GOLDSBY.....1946-49
Chicago Bridge & Iron Co., New York, N. Y.

Representing Associate Membership

D. E. STEARNS.....1948-51
The D. E. Stearns Co., Shreveport, La.

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The Holcombe Co., Shreveport, La.

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Ebasco Services, Inc., New York, N. Y.

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Loyola University, Chicago, Ill.

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Behavior of Hydrogen in Steel During and After Immersion in Acid*

By DR. LAWRENCE S. DARKEN and DR. RODNEY P. SMITH

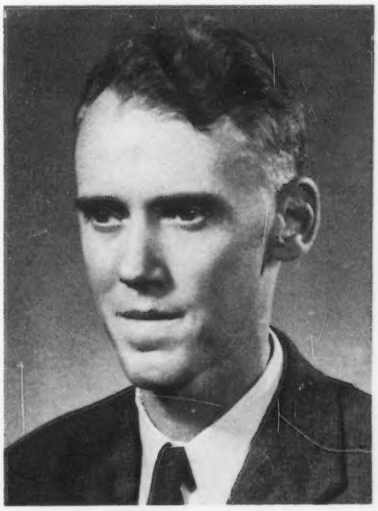
WHEN A PIECE of steel is immersed in a solution of an acid with which it reacts to liberate hydrogen, some part of this hydrogen enters into, or may even pass through the steel. On the other hand, when such a piece is removed from the solution and held in air, the hydrogen which it contains tends to diffuse out. Since the presence of a large concentration of hydrogen may have a significant influence on the properties of the steel, a knowledge of the processes by which it diffuses in or out is desirable. For convenience, these processes may be divided into two classes, stationary or non-stationary.

The stationary state may be associated with the passage of hydrogen through a diaphragm; if conditions are maintained constant, the rate of passage usually becomes constant (stationary) after sufficient time. This state is described by the permeability constant or permeability, designated P, which is the quantity of hydrogen (cc at NTP) transferred in one second through a diaphragm 1 mm thick and 1 cm^2 in cross section. This permeability may be expected to depend upon temperature, the nature of the steel and the boundary conditions, the latter including the nature of the surface and, of the acid medium in contact with one side; it might also depend upon the nature of the gas on the other side and on the thickness of the diaphragm.

The non-stationary state is associated with the rate at which a solid steel object absorbs hydrogen when immersed in an acid solution, or loses hydrogen when subsequently removed from the acid. This non-stationary diffusion phenomenon usually is described by the boundary conditions and the diffusion "constant" or diffusivity, designated D. This diffusivity is defined by Fick's Law which for the linear case with constant diffusivity may be written

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

where x is distance, t time and C concentration. This law is essentially a statement that any hydrogen which enters a small volume element either comes out or stays there. The diffusivity in general depends upon temperature, the nature of the diffusing substance, and the nature of the medium. Occasionally it is regarded as independent of concentration; unfortunately this cannot be assumed without proof, so that the diffusivity of hydrogen in steel must be regarded as a function of temperature, the nature of



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the steel and the amount of hydrogen present at the moment.

Experiments described here were therefore of two principal types, one designed to measure the permeability of steel to hydrogen, the other to measure the saturation concentration and diffusivity of hydrogen in steel, in each case with particular reference to factors associated with the solution in which the steel was immersed.

Experimental

Diaphragm type measurements were made in a manner similar to that described in the literature. The method consists essentially of exposing one side of a steel diaphragm to an acid (or other aqueous) solution and collecting and measuring the hydrogen which diffuses through and out the other side.

Discs (usually 1.5 inches diameter) were used, mounted in heads as depicted in 1A in Figure 1. The disc was mounted between two rubber washers, the lower of which was encased in lead foil carefully spun to fit so that no hydrogen would be lost by diffusion through the rubber; a very small amount of beeswax-rosin cement was used on this lead foil to prevent leakage. The glass cylinder containing the acid solution and connected to the main reservoir in the bottle, was ground and tapered at the lower end so that a well defined area of contact between acid and specimen was obtained with minimum attack by "wedge effect." The diffused hydrogen was measured by displacement of butyl phthalate from the glass bulb into the calibrated burette. The usual procedure was to mount the disc in the head, attach the burette (by cement), fill the burette nearly to the top with butyl phthalate, and place the assembly in an air thermostat overnight to test for leakage; if no visible change of position of the meniscus was detected in this period, the assembly was considered tight. The glass tube was then partially filled with nitric acid (1 to 3) and left one minute to etch the specimen, which was then rinsed with distilled water but not dried. Part of the acid (or other) solution to be used was then added; time was counted from this point. The inverted bottle was then placed in position and the remainder of the solution (previously brought to the proper temperature) was added through the overflow outlet. The whole assembly then was replaced in an air thermostat, and the rate of permeation followed by measuring the position of the butyl phthalate meniscus in the burette. If the amount of evolved (as well as diffused) hydrogen was to be measured the solution was brought up to this outlet; the evolved hydrogen was measured by displacement of the solution (the vent being closed) which was received in a graduated cylinder. The experiment was continued from a day to several weeks, duration depending on rate of attack and permeability.

The electrical potential of the steel specimen in the solution was measured by attaching a wire to the brass head and inserting a silver chloride half-cell in the overflow outlet. Potential of this half-cell against a hydrogen electrode (the latter in the same solution as the steel specimen) also was determined. Potential of the specimen against a hydrogen electrode in the same solution was obtained by subtraction of these two potentials. Direct measurement of this potential was not made because it is rather cumbersome and the hydrogen electrode is subject to poisoning by the products of reaction of steel with acid.

In order that the method described should successfully measure the permeability and potential under well defined conditions, several precautions must be taken; among them are:

1) The acid (or other solution) must stay at essentially fixed concentration. Insofar as possible the solution was changed as frequently as deemed necessary. Its pH, which was followed regularly, was held constant within 0.1 unit where possible; in the case of strongly acid solutions, used only over a few hours, this was possible by frequent changes during the day. In solutions of high pH it was easily achieved by daily change. In some cases a period greater than a day was required and the overnight change in pH was somewhat greater than desired; in a few such cases the potential of the specimen was measured directly against a hydrogen electrode and found to differ by only a few millivolts from that observed when a fresh solution was added.
2) The precentage change in thickness of the diaphragm should not be excessive. Pitting is particularly bad, because it leads to uncertainty in the value to be taken for average thickness. To minimize this error, a thicker diaphragm was used for stronger acids. In solutions of intermediate pH (about 4) even a thin diaphragm

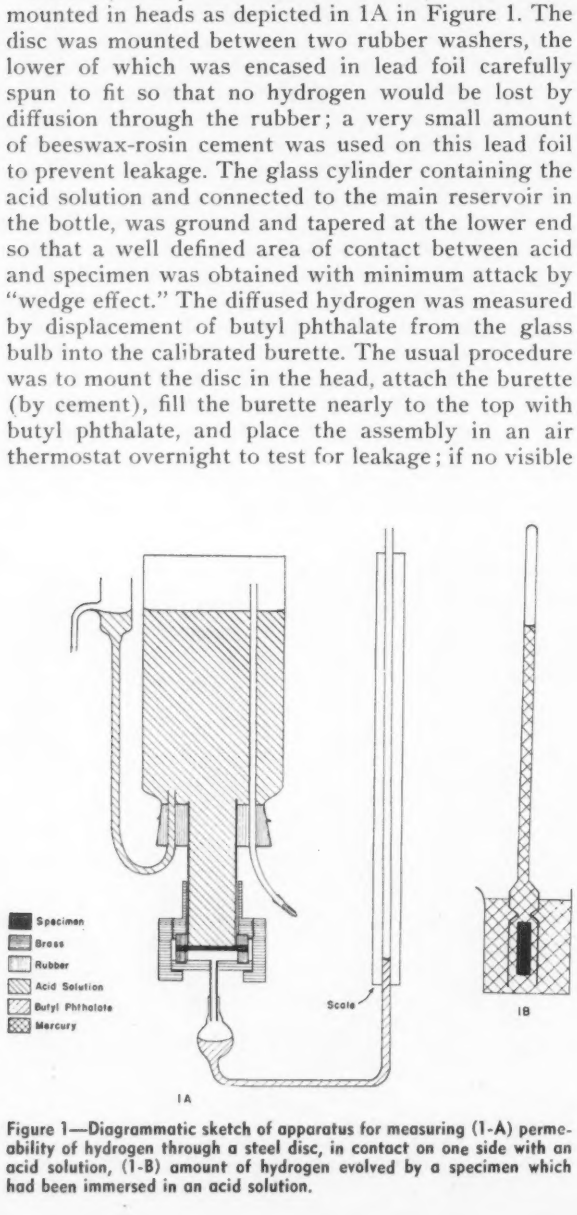


Figure 1—Diagrammatic sketch of apparatus for measuring (1-A) permeability of hydrogen through a steel disc, in contact on one side with an acid solution, (1-B) amount of hydrogen evolved by a specimen which had been immersed in an acid solution.

has a long life, yet its permeability may be measured with some precision.

3) The thickness of the diaphragm should be small compared to its diameter in order that the loss of hydrogen from the edge be insignificant. For a steel which dissolves rapidly in acid, the only way in which this and the foregoing condition can be met is by proper selection of pH.

The measurement of solubility and diffusivity is simple in principle. The specimens (usually cylindrical, but sometimes in the form of a disc or sheet, the latter being coiled) were cleaned by a short treatment with nitric acid (1 to 3), then rinsed and immersed in the selected solution. An iron wire for measurement of electrical potential was soldered to one or more of the group to be immersed simultaneously. This wire was covered with a tubular rubber insulator, the end nearest the specimen and the solder being coated with rosin-beeswax mixture so that neither wire nor solder came into contact with the solution. At appropriate intervals* one specimen was removed, rinsed successively in distilled water, alcohol, acetone and ether; it was then placed in a specially designed burette (1B in Figure 1) which was filled with mercury; the burette was then inverted and the open end placed in a beaker of mercury so that the hydrogen evolved by the specimen was collected by displacement of mercury. These operations were performed as rapidly as consistent with thorough rinsing (about one minute) and with care that no air bubbles were entrapped in the burette. Because a large range of hydrogen content was covered, it was necessary to have a considerable range in diameter of the top portion to measure the hydrogen, as well as a variety of sizes and styles of the bottom portion to accommodate the specimen. A schematic diagram of a burette is shown in 1B in Figure 1.

Usually several such burettes, each containing a specimen, were placed in a single beaker of mercury. If the rate of evolution at 35° C. was to be followed, the assemblage was placed in the air thermostat, and the position of the mercury meniscus as well as the barometer and the height of the mercury column in the burette was measured at appropriate intervals. If only the total amount evolved was to be measured, the assemblage was left overnight on an electric hot plate, heated and held at 170° C. A little ceresin wax was placed on the mercury to prevent its evaporation. Preliminary investigation indicated that four or five hours at this temperature was sufficient—i.e. not more than 1 or 2 percent more hydrogen would be evolved even if the time range was as much as three days. Many specimens were held for two days at 170° C. The final amount of hydrogen was the same as after overnight treatment.

A high temperature vacuum extraction apparatus was available so that gas could be extracted from the sample in vacuum at temperatures up to 800° C.; but, as this method was time-consuming, only a relatively small number of specimens were treated in this "hot extractor."

Throughout this article the unit adopted for expressing hydrogen content is cubic centimeters of hydrogen under standard conditions per gram of steel (cc/g). In mill practice hydrogen content usually is expressed as percent. The conversion may be made readily by the following relation: 1 cc/g hydrogen = 0.00899 percent; or 0.0001 percent hydrogen = 0.0112 cc/g = 0.087 volumes per volume.

The range covered in this report is approximately from 0.01 to 0.6 cc/g or from 0.0001 to 0.005 percent. It is to be noted that the usual residual hydrogen in commercial steel is in the vicinity of the lowest hydrogen content of this investigation and that highest hydrogen content (after acid immersion) is roughly ten to a hundredfold residual hydrogen content commonly found in finished steel.

Composition of the gas evolved at temperatures up to 170° C. from a number of samples previously immersed in acid was determined by analysis in a micro-apparatus. Gas collected at room temperature was not less than 97 percent and averaged 98 percent hydrogen, the balance being principally hydrocarbons and nitrogen. That collected at 170° C. was not less than 95 percent hydrogen. All these analyses were made on gas from specimens which yielded more than 0.1 cc (NTP) gas per gram steel. It is possible gas from specimens yielding a smaller volume might have contained less hydrogen but it seems safe to conclude that in all experiments here reported the gas collected at temperatures up to 170° C. was essentially hydrogen.

The gas collected in the hot extractor at 450° C. (all specimens analyzed in the hot extractor previously had been heated at 170° C.) contained a smaller percentage of hydrogen, ranging from 45 to 96 percent and averaging about 80 percent. Subsequent extraction at still higher temperatures yielded relatively small amounts of gas which frequently contained as little as 40 percent hydrogen.

Of the several dozen specimens treated in the hot extractor, all yielded a residual hydrogen content (i.e. hydrogen remaining after the 170° C. extraction) between 0.003 and 0.03 cc per gram and averaging very nearly 0.01 cc per gram. Seldom did the 18-hour 170° C. extraction fail to yield at least 90 percent of the hydrogen which could be extracted in vacuum at temperatures up to 800° C. This may appear surprising in view of statements in the literature as to the difficulty of removing residual hydrogen from steel; however, it is to be remembered the hydrogen content induced by acid pickling is large compared to that

Table I. Alternate Extraction (600° C, 2 Hours) and Exposure to Air of 2-inch Length of ⅜-inch Round (27 grams).

	Original Extraction	1st Reextraction	2nd Reextraction	3rd Reextraction
cc (NTP) of gas	0.155	0.111	0.114	0.123
$\%H_2$	55	42	53	56
%CO	25	42	26	25
$\%CO_2$	4	4	4	4
$\%N_2$ (by diff.)	16	12	17	15

* Since the amount of hydrogen absorbed was usually proportional to the square root of time up to saturation, the time intervals selected were such that the square root of time of immersion was equally spaced, e.g. a specimen would be removed at 1, 4, 9, 16 hours.

normally present in a finished commercial product.

An advantage of extraction at 170° C. over higher temperature is that water on the surface is evaporated and recondensed in the usual method, whereas at high temperature such water way react with iron or carbon, thus yielding a fictitiously high hydrogen content. To minimize this source of error, all specimens run in the hot extractor first were sanded or filed to a smooth finish. Even so, if such a specimen were extracted at 600° C. until no further gas was given off (in a one-hour period), it was found that, if it were exposed to air and then reextracted, appreciable gas was evolved. In the case of one specimen (⅜ inch round) this alternate extraction and exposure to air (humidity about 60 percent) was repeated three times, with the results shown in Table I. The data in the first column refer to the rod in "as received condition"—i.e. it had had no additional acid treatment. In the short time allowed for exposure to air these gases hardly could diffuse into the interior of the specimen, consequently it seems safe to conclude that the amounts in the last three columns represent gas absorbed on the surface or the reaction products thereof, for the apparatus blank is only about 0.002 cc. Although the hydrogen evolved on reextraction corresponds to only 0.002 cc per gram, the sample is quite massive compared to sheet. If it properly may be assumed that this all represents surface adsorption, then the amount so adsorbed is 0.004 cc per cm². On a sheet 0.01 cm thick this corresponds to 0.1 cc per gram, a reasonably large amount.

A similar experiment was performed on some low carbon sheet (hot rolled); the specimen weighed 32 grams and was 0.05 cm thick. Surface adsorption amounted to 0.003 cc hydrogen per cm². Another similar experiment with hot rolled rod yielded 0.002 cc hydrogen per cm². Such error may be avoided partially by heating sheet samples first at low temperature in the hot extractor and discharging the water vapor before raising the temperature.

Reproducibility

Although a general idea of reproducibility of any of the series of experiments may be estimated from the departure of individual points from the best smooth curve, a few special experiments were run to check the reproducibility.

A set of ten 2-inch lengths of ¼-inch rounds of ingot iron (commercial Armco) were immersed in normal sulfuric acid. These were removed in pairs at various times and the hydrogen extracted in the usual manner, with the results shown in Table II. From these data it seems safe to conclude that steel

Table II. Reproducibility of Absorption and Extraction of Hydrogen: ¼-inch Rounds in N H_2SO_4.

Time of Acid Immersion, (Hours)	Average Weight of Specimens (Grams)	Amount of Absorbed Hydrogen (cc NTP per Gram)	
		A	B
0	12.5	....	....
1.96	12.4	0.016	0.015
7.55	12.3	.024	.022
24.7	12.0	.057	.057
144.4	10.1	.103	.107
233.0	8.7	.097	.105

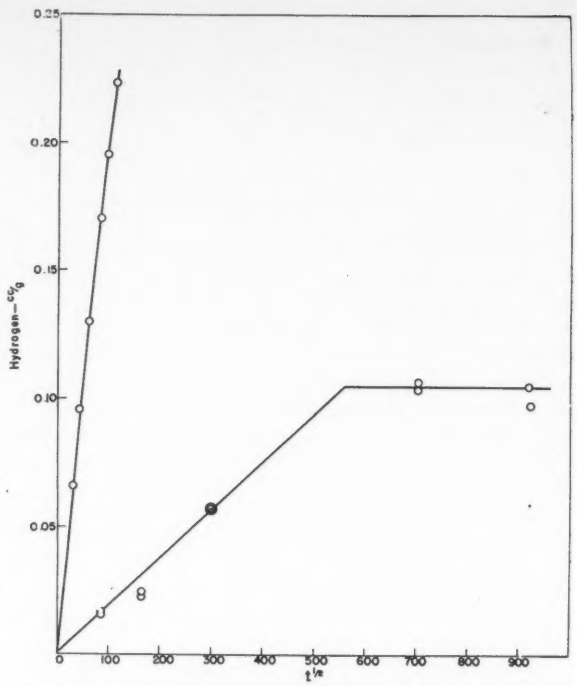


Figure 2—Amount of hydrogen absorbed (cc at NTP per gram steel) plotted against square root of t (period immersed in seconds); lower curve, ingot iron in 1N H_2SO_4; upper curve, SAE 1020 bar in 10N H_2SO_4; ¼-inch rounds. (1 cc NTP per gram = 0.00899 % H.)

specimens from the same rod, identically treated (with respect to acid immersion), absorb essentially the same amount of hydrogen within a rather small limit of error. However, when they are plotted (amount of hydrogen versus square root of time), as in Figure 2 (lower curve), the departure of the second pair from the smooth curve is greater than might be expected from the agreement of the pair with each other; this departure possibly can be attributed to depletion of the acid despite frequent changes, the acidity being slightly less at the time this pair of samples was removed. No departure greater than 0.01 cc per gram was found.

A similar series of cylindrical specimens, this time of commercial SAE 1020 cold rolled bar, was immersed in 10 normal H_2SO_4 solution for various times. The plot of the data in Figure 2 (upper curve) shows that the points fall on a smooth curve well within 0.01 cc per gram. Slightly greater discrepancy from such smooth plots in some of the results subsequently presented probably is to be ascribed either to depletion of acid or to the use of steel specimens which were nominally but not actually identical.

Precision of the permeability measurements is best judged from long time measurement. In strongly acid solutions the time was limited by the rapid dissolution of the diaphragm. For example, a steel diaphragm originally 0.095 cm thick was exposed on one side (exposed area, 5.74 cm²) to 10 normal H_2SO_4 at 35° C.; after one day hydrogen was transmitted at the rate of 0.151 cc per hour and the average thickness (as estimated from the evolved hydrogen) was 0.0795 cm; on the third day the rate of transmission

had increased to 0.195 cc per hour but the mean thickness had decreased to 0.0636 cm. The permeability based on these figures is 5.8×10^{-5} and 6.0×10^{-5} cc (NTP) H_2 per cm² per sec. per mm thickness for the second and third days, respectively. A permeability experiment of three weeks' duration was performed using a buffered solution of pH 4 in contact with one side of a cold rolled (SAE 1020) disc. After allowing a few days for establishment of steady state, the rate of transmission of hydrogen was 0.035 cc per hour ($P = 1.36 \times 10^{-6}$) for the first week, which decreased to 0.030 cc per hour ($P = 1.17 \times 10^{-6}$) for the second, and 0.028 cc per hour ($P = 1.09 \times 10^{-6}$) for the third week. Thickness of the specimen decreased from 0.0960 to 0.0950 cm as measured by a micrometer; the change in mean thickness (from weight loss) was 0.003 cm. Numerous other permeability experiments were continued for a comparable length of time, the variation of 20 percent in measured permeability was comparable to the case cited. Several series of results are shown graphically in Figure 3.

The effect of size of specimen was determined in both permeability and diffusivity types of experiment. In the permeability measurements the rate of transmission of hydrogen was expected to be inversely proportional to the thickness of the diaphragm (other things being constant). The discs used were cut (at right angles to direction of rolling) from 1½-inch cold rolled steel bar (SAE 1020). The acid solution was pH 4.4. The rate of transmission of hydrogen, through an area of 5.9 to 6.2 cm², during the second week is given in Table III, which shows that although the permeability (which may be regarded as the transmission rate corrected for thickness) is not found experimentally to be identical in all cases, the variation is comparable to the reproducibility of the measurements.

Bardenheuer and Thanheiser[1] carried out an extensive investigation of the permeability of hydrogen through diaphragms of an "ingot steel" (of the composition C0.09 percent, Mn—0.39 percent. S—0.029 percent, Si—0.03 percent, Cu—0.18 percent) which were exposed on one side to a sulfuric acid solution (387 grams per liter) at 25° C. The permeability (as calculated from data presented graphically) is as follows:

Thickness (mm)	0.75	0.80	1.5	2.0	4.0	8.0
$P \times 10^{-6}$	2.1	2.1	1.7	2.0	2.8	1.8

There is no drift of P with thickness, and this fact is taken to indicate that the measured permeability is a true permeability in the sense that the resistance to transmission of hydrogen lies in the steel itself and is not localized at the surface to any appreciable extent.

A series of tests was performed on rods of different diameter made by machining all specimens from the same ⅜-inch round; the final diameters in inches were 3/8, 3/16, 3/32, 3/64. They were immersed in a buffered solution of pH 3.2 for various times. The results are shown in Figure 4, where volume of

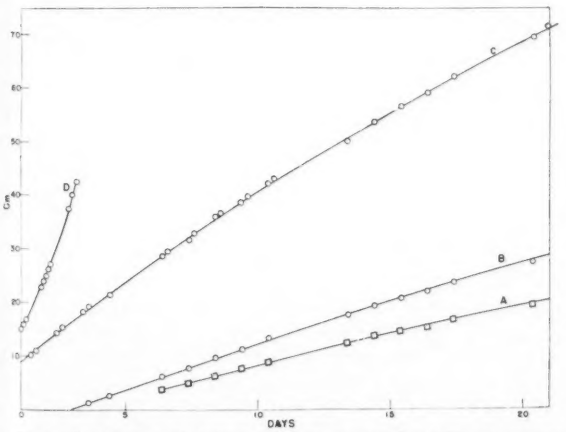


Figure 3—Amount of hydrogen (1 cm on scale = 4.27 cc) passing through a steel disc in contact with an acid solution plotted against time in days. (measurements in mm.)

Curve	Solution	Disc Original Thickness	Disc Diameter In Contact
A	pH 6.25	0.965	27.6
B	5.47	0.965	29.0
C	4.33	0.960	27.5
D	10N H_2SO_4	0.957	27.0

Table III. Permeability of Cold Rolled Steel Diaphragm Immersed on One Side in Solution at pH 4.4 at 35° C.

Thickness of Disc, mm	Rate of Transmission cc/Hr.	Permeability P
0.96	0.028	1.09×10^{-6}
1.88	.0130	0.99
5.08	.0068	1.40

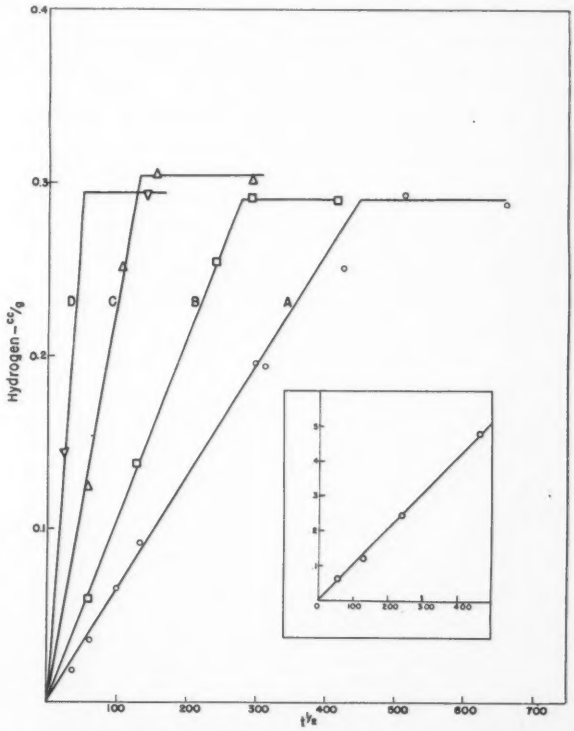


Figure 4—Amount of hydrogen (cc NTP per gram) absorbed by a cylinder of diameter (A) ⅜-inch; (B) 3/16-inch; (C) 3/32-inch; (D) 3/64-inch from a solution of pH32 plotted against square root of time immersed (seconds); Inset: Plot of square root of time for saturation against diameter of specimen. (1 cc NTP per gram = 0.00899% H.)

hydrogen per gram is shown as a function of square root of time. Note that a linear relation is indicated until saturation is reached, and this solubility is the same in all. If permeability is independent of size, the slope of each of these lines would be inversely proportional to the diameter of the round; that this is so may be seen from the inset of this figure. This is regarded as conclusive evidence the hydrogen absorbed is truly absorbed into the interior of the steel and the experimental error due to surface adsorption is small.

The distribution of hydrogen during steady state permeation cannot be determined by section and analysis of the diaphragms since hydrogen would be lost in the process. However, total hydrogen content was determined (as a function of time) for discs only one side of which had been exposed to acid. Steel specimens (discs — 0.5 cm thickness—of SAE 1020 steel) were waxed on the edge and inserted in a rubber socket. One side then was exposed to molal citric acid the other to air. The hydrogen content is shown graphically in Figure 5 (lower line) and compared therein to similar data for fully immersed discs. Note the saturation value (C_S) for the half exposed is 85 percent as great as for the fully exposed discs. This is direct evidence that the diffusion of hydrogen is "abnormal" because if the hydrogen content varied linearly from one side to the other in the half exposed, the steady state hydrogen content would clearly be only half as great as for the fully exposed specimens.

At steady state it is almost certain the true driving force (as distinguished from concentration gradient) is indeed constant. If it now be assumed that the permeability is proportional to the gradient of the lattice-dissolved hydrogen (C_o), that is, that the true diffusivity (D_o) is a constant (for the same steel at the same temperature), then the form of the relationship between total hydrogen (C_S) and C_o may be found from the data of Table IV because, on the assumption C_o is proportional to P. A plot of C_S vs P is shown in Figure 6. If the assumptions above are correct, the abscissa in this diagram also may be regarded as being proportional to distance in the half exposed disc. On this basis, it would be predicted that the steady state hydrogen content of the half exposed disc would be considerably greater than half that of the fully exposed disc—in fact, the area under this curve corresponds to 80 percent of the saturation value whereas by direct measurement (Figure 4) it was 85 percent. This agreement is regarded as very satisfactory and as leaving no doubt that the concentration of hydrogen in the cold worked diaphragms is by no means linear at steady state but must be of the general form shown in Figure 5.

The rate of evolution of absorbed hydrogen was found to be slower than the rate of absorption. In the ordinary type of diffusion (P proportional to C_S) the two rates are the same; but as already pointed out, in steel C_S is not proportional to P (Figure 6). By utilization of the type of reasoning discussed in the Appendix it may be shown that the ratio of outgoing to ingoing rate of hydrogen is related to the type of the C_S vs P curve. If the ratio of the shaded

Table IV. Solubility and Permeability of Hydrogen in SAE 1020 Steel as a Function of pH.

Solution pH	E	Solubility cc NTP/g C_S	$\lambda = C_s/\sqrt{t_s}$	$P = 2.20\ \lambda/\sqrt{t_s}$	Log P
1.28	0.225	0.371	0.00098	5.7×10^{-6}	—5.24
3.16	.200	.317	.00065	3.0×10^{-6}	—5.52
5.43	.168	.22	.00029	0.85×10^{-6}	—6.07
7.09	.117	(.04)	.00005	$.12 \times 10^{-6}$	—6.92
8.04	.050	(.008)	.000006	$.011 \times 10^{-6}$	—7.96

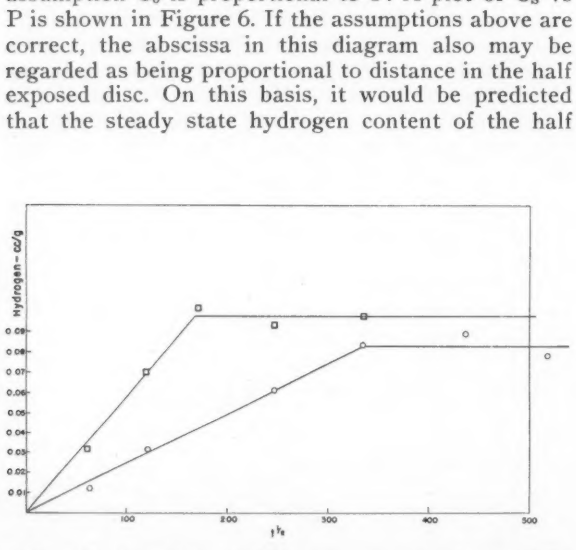


Figure 5—Comparison of indirect measurement of permeability through similar discs exposed on both sides (upper) and on one side only (lower) to molal citric acid at 35° C. (1 cc NTP per gram = 0.00899% H.)

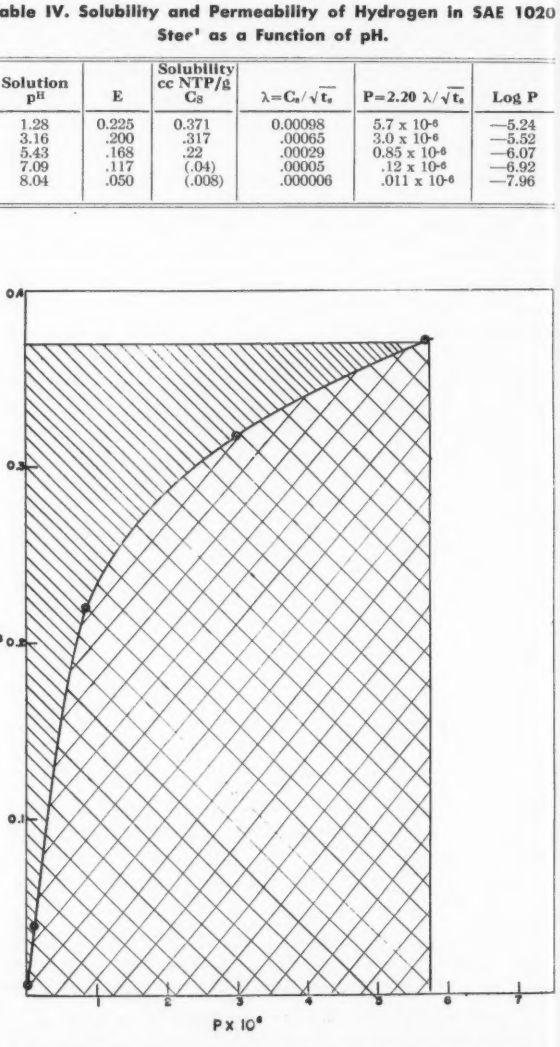


Figure 6—Saturation concentration C_S plotted against the permeability (P). This same plot also may be regarded as showing the relation between the concentration of hydrogen and distance during steady state permeation of a diaphragm. (1 cc NTP per gram = 0.00899% H.)

area to the sum of the shaded and cross-hatched areas (Figure 6) is designated F,

$$\frac{\lambda_i}{\lambda_o} = \sqrt{\frac{1-F}{F}}$$

where λ_i is the ingoing slope (i.e. $C_s/\sqrt{t_s}$) and λ_o is the initial outgoing slope. If F is 0.5 (ideal case) then $\lambda_i = \lambda_o$. In Figure 5, F = 0.20, and $\lambda_i/\lambda_o = \sqrt{\frac{1-0.2}{0.2}} = 2$.

As noted previously this ratio of areas (F) is identical with one minus the ratio of steady state hydrogen content of a half exposed and fully exposed diaphragm. For the steel of Figure 5, F is thus $1 - \frac{0.83}{0.97} = 0.15$, whence λ_i/λ_o is 2.4. The experimental comparison with identically the same steel is shown in Figure 7; the ratio of initial slopes observed is 2.2 which is in good agreement with that calculated.

Although in this case the initial rate of evolution of absorbed hydrogen is half the initial rate of absorption it is obvious from Figure 7 that a very long time indeed would be required for nearly complete evolution of the hydrogen, e.g. only 80 percent of the absorbed hydrogen was lost by this specimen in four days although this amount was absorbed in eight hours. Several such comparisons of ingoing and outgoing rates were made; all were similar in that the outgoing rate was much smaller than the ingoing rate at 35° C. Another typical example, on cylindrical specimens (3/16-inch diameter), similar to those used in the pH series, immersed in a buffer solution pH 3.25, is shown in Figure 8. The evolution rate was measured on the final sample of the absorption rate series which subsequently was extracted at 170° C. to give the value shown. Five days were required for loss of half the hydrogen at 35° C. whereas only seven hours were required for the absorption of half. Another example is included in Figure 9.

This slow rate of loss of the final traces of hydrogen is in accord with the behavior already discussed.

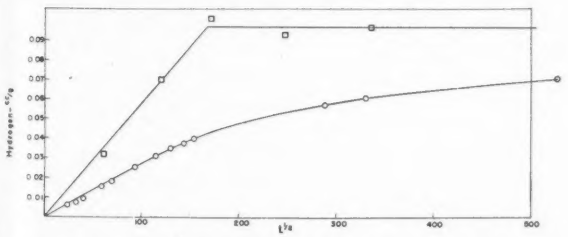


Figure 7—Comparison of rate of absorption of hydrogen from a solution of molal citric acid with rate of evolution (lower curve) both at 36° C. (1 cc NTP per gram = 0.00899% H.)

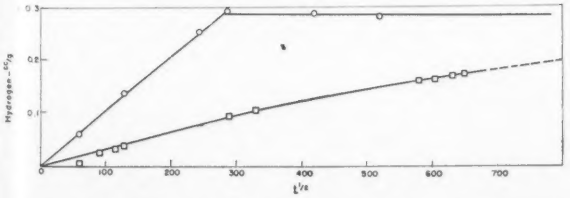


Figure 8—Comparison of rate of absorption from a solution of pH 3.25 with rate of evolution (lower curve) both at 36° C.

By reference to Figure 6, it can be seen that as the amount of total hydrogen decreases the amount of lattice dissolved hydrogen (the gradient of which is the driving force) decreases much more rapidly, and thus escape is very slow.

In order to determine whether the evolution rate is sensitive to the medium in which evolution occurs, two similar specimens of ⅜-inch round were immersed in molal citric acid until saturated, as determined by previous tests. One was placed in a burette containing mercury (regarded as an inert environment), the other in a similar burette containing aqueous sodium carbonate solution. Both were placed in a water bath at the boiling point; the actual temperature of the mercury was 95° C. and of the solution 90° C. The course of evolution in the two cases is depicted in Figure 10; the slight difference is probably due to the 5° C. temperature difference. It is of interest to note that extraction of these specimens at 170° C. yielded further only 0.001 cc (NTP) /gr.; hot extraction at temperatures up to 600° C. yielded further only 0.01 cc per gram as compared to 0.34 cc per gram evolved at 90-95° C.

To further test whether immersion in water is more effective than in air both at the same temperature (100° C.), a separate series of experiments was performed. Specimens of cold rolled steel rod were immersed in molal citric acid until saturated. Those of one set, on removal from the acid (and rinsed) were held in boiling water for various times, then inserted in the usual burettes and extracted at 170° C. The other set, on removal from the acid, was placed in an empty test tube immersed in boiling water, again for various times, and then similarly extracted. The amount of hydrogen removed by either treatment at 100° C. was determined as the difference between the known initial and measured final content. These results are shown in Figure 9 and com-

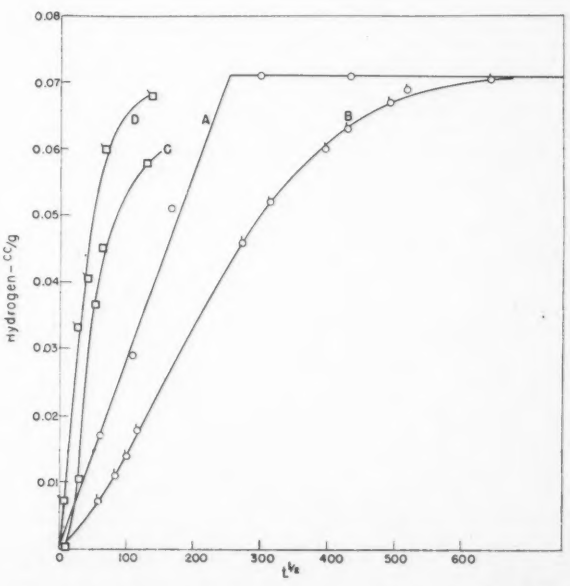


Figure 9—Comparison of rate of absorption (curve A) at 35° with rate of evolution (B) at 35° into mercury and (C) into air and (D) water bath at 100° C.

pared with the rates of absorption and evolution at 35° C. The difference between water and air-treated specimens is not large, and may be attributed to the fact that considerable time was required to heat the specimens to 100° C. in air.

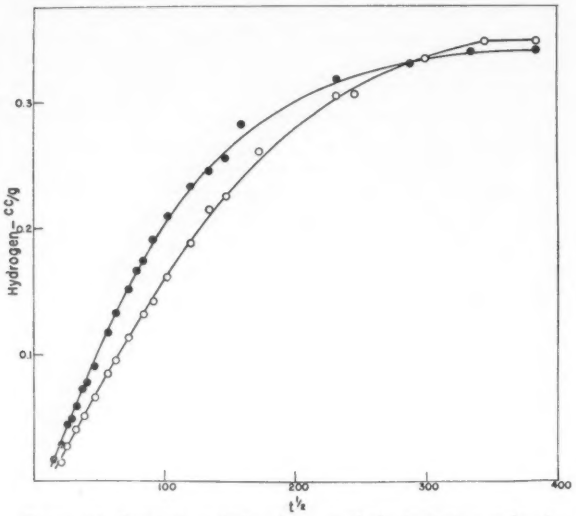


Figure 10—Rate of evolution from similarly treated samples immersed in mercury at 95° (upper) and in carbonate solution at 90° C (lower curve). (1 cc NTP per gram = 0.00899% H.)

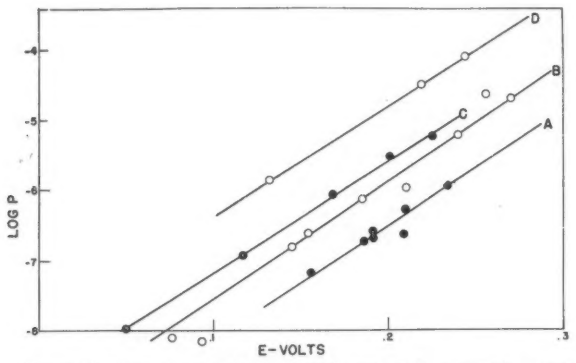


Figure 11—Log of permeability plotted against E, potential against hydrogen electrode, for (A) low carbon strip at 35°; SAE 1020, (B) measured directly at 35° C; (C) calculated from mathematical theory; (D) measured at 75° C. The slope of line B, drawn empirically, is 0.059; the theoretical slope is 0.061.

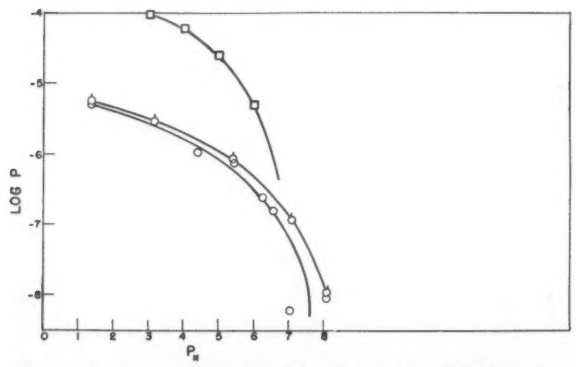


Figure 12—Comparison of direct (lower) and indirect (middle) measurements of permeability; the steep curve represents direct results from data of deBoer and Fast.

Effect of Factors Relating to the Solution

Effect of acidity (pH) on permeability was determined by use of citrate-phosphate buffer solution as well as of sulfuric acid. The diaphragms were from the same round of SAE 1020 steel as those used previously. The observed permeabilities are given in Table V, and plotted in Figure 11. The runs with sulfuric acid were not entirely satisfactory since the diaphragm (of this particular steel) was largely consumed and thus gave an ever increasing rate of transmission, so that it was impossible to determine whether a steady state was ever attained; the data in the table pertain to conditions when the diaphragm was eaten nearly half through; the permeability listed was calculated from the thickness at this time as estimated from the amount of dissolved iron. The run with pH 7.97 yielded an erratic rate of transmission; the value given for P is an average. All other runs were quite satisfactory in that a uniform steady state was attained, and the rate of transmission was followed for a long time (three days for citric acid, three weeks for all others). Some of the original data are plotted in Figure 3.

If it be assumed that the electric potential (E) is a measure of hydrogen over-voltage, then the fugacity (f = pressure for ideal gas), of hydrogen at the surface exposed to the solution is related to E by the equation (at 35° C.)

$$E = 0.0611 \log f^{1/2}$$

If further, the permeability P is proportional to the square root of fugacity in the range covered, as it is proportional to the square root of pressure up to 1000 atmospheres at higher temperatures, then

$$E = 0.0611 \log P - 0.0611 \log P_o$$

where P_o is the permeability of the diaphragm to hydrogen at atmospheric pressure. If this equation is valid, a plot of log P vs E would be linear with slope = 0.0611. The observed slope of the line B as drawn in Figure 11 is 0.059; the agreement is well within experimental error as judged from the departure of individual points from the line.

Similar data at 75° C. are included in Figure 11. The observed slope is 0.064, and the theoretical is 0.069.

In Figure 12 the above permeabilities are plotted against pH. Also included in Figure 12 are the indirectly determined permeabilities discussed in the next section and the data of DeBoer and Fast.

The effect of pH on solubility and permeability was measured on 2-inch lengths of ⅜-inch round cold rolled SAE 1020 steel, immersed in citric acid and citrate-phosphate buffer solutions. The results are shown graphically in Figure 13. The specimens in pH 7 turned green after the last point recorded

Table V. Permeability (P) at 35° C. as Function of pH of Solution

Solution	pH	E	P x 10⁶	Log P
10 N H_2SO_4	....	0.25–0.29	16.	—4.69
N H_2SO_4	0.30	0.256	23.	—4.64
Molal citric acid	1.37	0.240	6. (5.0–6.9)	—5.22
Citrate-phosphate buffer	4.40	0.210	1.04	—5.98
Citrate-phosphate buffer	5.44	0.185	0.75	—6.12
Citrate-phosphate buffer	6.25	0.154	0.24	—6.62
Citrate-phosphate buffer	6.58	0.145	0.16	—6.80
Citrate-phosphate buffer	7.02	0.093	0.006	—8.22
Citrate-phosphate buffer	7.79	0.077	0.008	—8.1

in the figure, and the hydrogen content of subsequent samples was very much lower than that of the last shown. The data are summarized in Table V.

The permeability here tabulated is calculated from the slope, λ, of the C vs $t^{1/2}$ plot. The equation used, $P = 9.8 \frac{\lambda^2 a^2}{Cs}$, is taken from the appendix, inserting equation II-4 in the relation $P = 10\rho D_o C_o$; the density, ρ, is taken as 7.8 g/cm³. By insertion of the numerical value of the radius, $P = 2.20 \lambda / \sqrt{t_s}$. Log P, thus calculated is plotted vs E as curve C of Figure 10; the slope 0.063 is again in good agreement with the theoretical value 0.0611. The solubility, C_s (i.e. steady state concentration of hydrogen) is also shown as a function of pH in Figure 14.

The effect of temperature on permeability was measured in a similar manner except that a water thermostat was used for higher temperatures and ice-water for 0° C. The steel discs were from the same bar as those used in the pH series. The results are shown in Table VI.

This effect also was investigated by Bardenheuer and Thanheiser[1] on a diaphragm, of the same steel described previously, 1.2 mm thick, exposed on one side to sulfuric solution (387 gr. per liter), with the following results:

Temperature °C	20	30	40	50	60	70	80
$P \times 10^6$	2.03	2.56	3.93	5.16	9.1	11.8	18.6

The temperature coefficient is about the same in the two cases—the permeability doubles for about 20° C. rise in temperatures (except in the case of the pH 4.4 solution where there is a large change in E). The absolute values of P found by Bardenheuer and Thanheiser are considerably smaller than those encountered in these investigations (using sulfuric acid) whereas they might be expected to be larger in the stronger acid; this discrepancy probably lies in the nature of the steels. Again at 75° C. (as well as at 35° C.) the plot of log P vs. E is linear and has nearly the theoretical slope—as shown in Figure 11. Extrapolation of these two lines in Figure 11 to E = 0 would thus yield a value of the permeability of this steel to hydrogen at one atmosphere pressure.

This extrapolated permeability (using the line with the theoretical slope) is compared with the extrapolation of Smithell and Ransley's[2] data for high temperature (400 to 800° C.) in the following table, and in Figure 15.

Log Permeability, at t° and 1 Atm. Hydrogen, Extrapolated from

Temp.	This Investigation	S & R
35° C.	—9.14	—8.11
75° C.	—7.69	—7.33

One set of measurements on non-steady state dif-

Table VI. Hydrogen Permeability (Steel SAE 1020) as a Function of Temperature.

Temperature.....	0°		35°		55°		75°	
Solution	$P \times 10^6$	E	$P \times 10^6$	E	$P \times 10^6$	E	$P \times 10^6$	E
Normal H_2SO_4.....	5.2	0.288	23.	0.256			78.	0.244
Molal citric acid...			6.	0.240			34.	0.219
pH 4.4.....			1.04	0.210	1.31	0.171	1.46	0.132

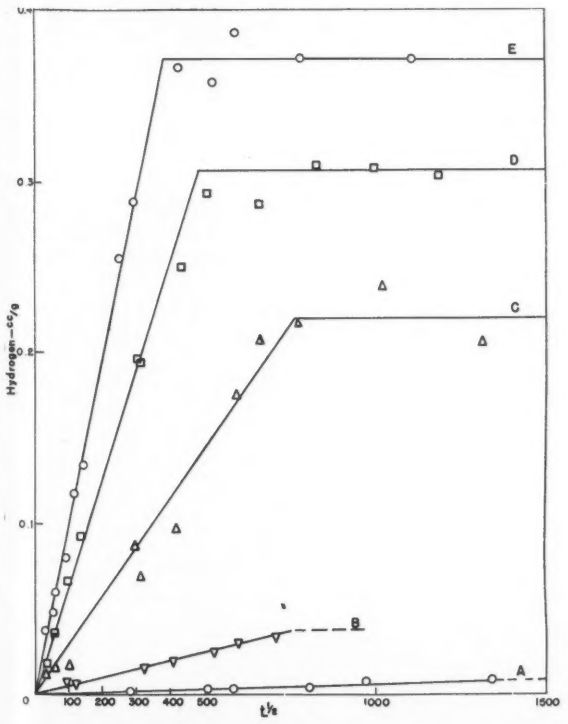


Figure 13—Amount of hydrogen absorbed by similar specimens immersed in a solution of pH (A) 7.92; (B) 7.09; (C) 5.43; (D) 3.14; (E) 1.38, plotted against square root of time of immersion. (1 cc NTP per gram = 0.00899% H.)

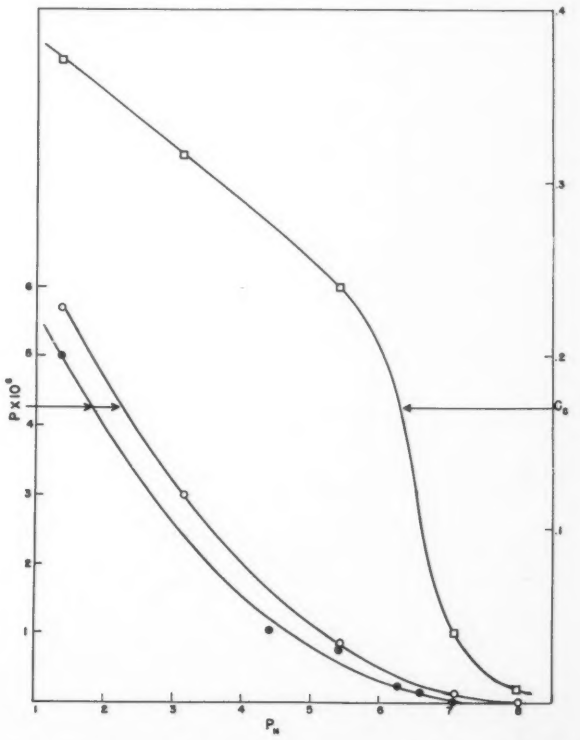


Figure 14—Direct measurements of P and C_s in relation to pH, and indirect evaluation of P (middle curve) derived from rate of absorption and C_s.

fusion was made at 100° C. on ¼-inch rounds immersed in normal sulfuric acid for various periods. These results are shown in Figure 16 and compared with the line representing similar experimental results at 35° C. As anticipated, hydrogen was absorbed more rapidly at 100° C.; the upward curvature is undoubtedly caused by the very rapid attack of the acid on the specimens—the last of which was about 50 percent consumed. Roughly it may be said that in a given time this specimen absorbed twice as much hydrogen at 100° C. as at 35° C.

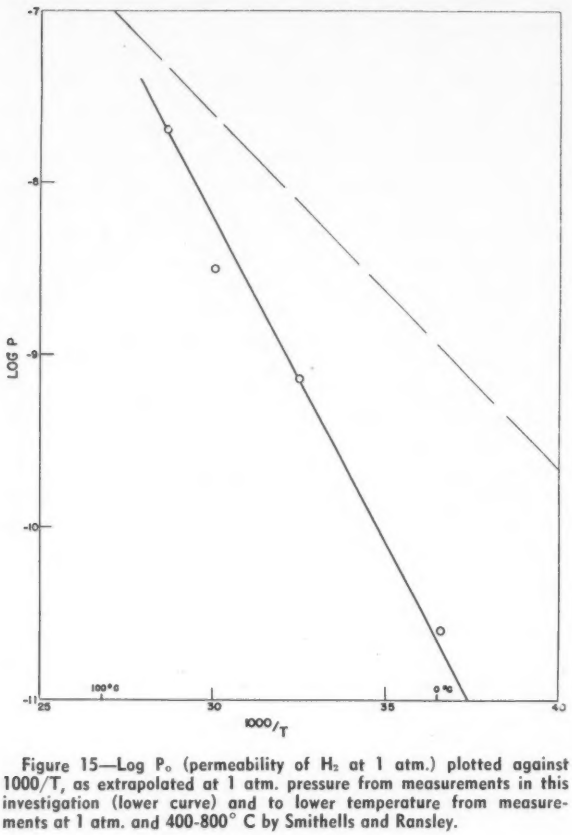


Figure 15—Log P_o (permeability of H_2 at 1 atm.) plotted against 1000/T, as extrapolated at 1 atm. pressure from measurements in this investigation (lower curve) and to lower temperature from measurements at 1 atm. and 400-800° C by Smithells and Ransley.

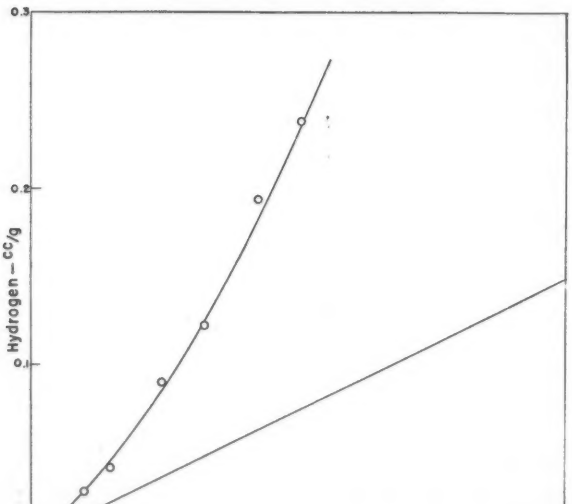


Figure 16—Comparison of rate of absorption at 100° C. (upper curve) and 35° C. (lower). (1 cc NTP per gram = 0.00899% H.)

The effect of inhibitors on permeability was marked. Only two inhibitors, quinoline ethiodide (0.1 percent) and "Nep No. 22" were tried, both with normal H_2SO_4; diaphragms of several different steels were used. Both these inhibitors reduced the permeability to a very low value, compared to that for the uninhibited acid. No numerical data are given since both permeability and electric potential were very erratic.

In one case 0.02 percent Nep was added in the middle of a permeability experiment; the permeability decreased from 1.8×10^{-6} to less than 0.01×10^{-6}. The potential E dropped from 0.21 to about 0.18 volt; but this drop of about 0.03 volt is not sufficient to account for the observed decrease in permeability.

It was found, in a few isolated experiments, that C_S is also decreased (by a factor of from 3 to 6) by the use of Nep in normal H_2SO_4 at 35° C. Addition of ferrous sulfate was found to have no significant effect on either the electrical potential or the amount of hydrogen absorbed.

Influence of Cold Work and Annealing

The effect of cold work on the solubility of hydrogen was found to be very pronounced. This effect was not discovered until the investigation was half completed, and hence in part of the work it completely masked or obliterated other effects. The most complete investigation was conducted by means of the non-steady-state method. A quantity of hot rolled rod (0.503-inch diameter) of the following analysis was procured: C, 0.15 percent; Mn, 0.38 percent; P, 0.014 percent; S, 0.035 percent; Si, 0.14 percent; H_2 (by hot extraction at 500° C.), 0.001 cc NTP per gram. This rod which was above 900° C. during all hot working operation, is hereafter referred to as "green rod." It was pickled for 30 minutes at about 90° C. in 7 percent H_2SO_4 solution, and baked three hours at about 250° C.; it was then cold reduced in five steps by means of commercial wire drawing dies, with no intermediate anneal. A portion was cut off after each reduction; the diameters and total percent reduction are as follows:

	Diam. (inches)	Percent Reduction
Green Rod	0.503	0
After 1st reduction	.460	16.5
After 2nd reduction	.419	30.6
After 3rd reduction	.369	46.2
After 4th reduction	.315	60.8
After 5th reduction	.249	75.9

Two-inch lengths of each were treated in normal sulfuric acid for various lengths of time, and the hydrogen absorbed was determined in the usual manner, with results shown in Figure 17. The time required for saturation of the more severely cold worked specimens was so long that the specimen was nearly consumed before it was saturated with hydro-

gen; in these cases, the saturation was measured similarly but on specimens whose centers had been drilled out. These were run in duplicate, one of each pair was immersed in acid for about twice as long as the other to make certain that saturation was attained; the saturation values thus determined are shown in Table VII. Remainder of the data are presented graphically in Figure 17 and in Table VIII.

Note the calculated permeability is remarkably constant—the greatest deviation from the mean being less than 10 percent—and certainly shows no trend; and this is in spite of a systematic variation of 20 microvolts in electrical potential. This permeability is smaller by a factor of ten than that found for somewhat similar steel immersed in the same acid in the pH series. Clearly this difference is not caused by degree of cold work, because it has been shown here that the permeability is independent of this factor. The difference must be ascribed either to a small difference in composition or heat treatment or to a difference in some unknown factor.

The effect of annealing subsequent to cold work proved to be much less than was anticipated. Some of the 75 percent cold reduced bar used in cold reduction series was annealed 72 hours at 840° C. It was then immersed in normal H_2SO_4 for various lengths of time. The hydrogen contents are shown in Figure 18 and compared with those for the annealed and hot rolled material of Figure 17. It was astonishing that this annealed material did not behave at all like the original hot rolled material. Although saturation was not attained (the acid attack being too severe over the very long times required) it can be estimated that C_s is greater (but probably not much greater) than 0.30, and hence the permeability is less than 0.24×10^{-6} as shown in Table VIII. Thus although cold reduction did not alter the permeability, annealing decreased it by a factor of five at least.

Interpretation of Results

The diffusivity (D) may be regarded under given conditions as a measure of the time required for a specimen of given size to absorb a given fraction of the hydrogen it would absorb in a very long time. In the case of constant boundary conditions and zero initial amount of hydrogen in the steel, the solution

Table VII. C_S as Determined on Drilled Samples.

	cc (NTP) After 30 Hrs.	Hydrogen per gram—C_s After 50 Hrs.
After 2nd reduction	0.120	0.117
After 3rd reduction	.175	.172
After 4th reduction	.278	.287
After 5th reduction	.417*	.386*

* Times of acid immersion were 18 and 36 hours. respectively.

Table VIII. Cold Reduction Series in Normal Sulfuric Acid.

Designation	E	$\lambda = C_s/\sqrt{t_s}$	$\sqrt{t_s}$	$P = 9.8\ \lambda\ a^2/\sqrt{t_s}$
Green rod	0.234	$(0.8_2 \times 10^{-4})$	(175)	$(1.28) \times 10^{-6}$
After 1st reduction	.240	1.45×10^{-4}	385	1.26×10^{-6}
After 2nd reduction	.241	2.41×10^{-4}	490	1.36×10^{-6}
After 3rd reduction	.244	3.09×10^{-4}	564	1.18×10^{-6}
After 4th reduction	.248	4.22×10^{-4}	587	1.29×10^{-6}
After 5th reduction	.254	7.08×10^{-4}	565	1.23×10^{-6}
Average				1.26×10^{-6}
After 5th reduction (annealed)	.225	2.72×10^{-4}	1100	0.24×10^{-6}

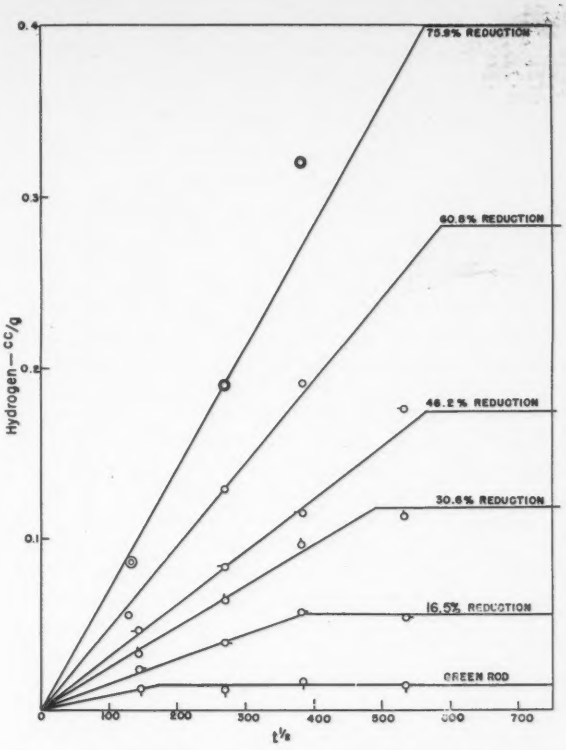


Figure 17—Effect of cold reduction on rate of hydrogen absorption and on C_S; wire stock immersed in N H_2SO_4 at 35° C.; green rod ½-inch diameter. (1 cc NTP per gram = 0.00899% H.)

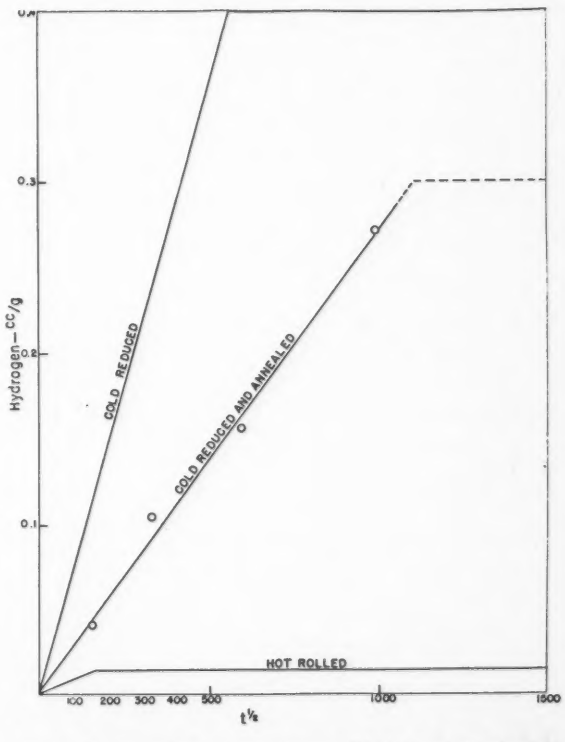


Figure 18—The effect of cold drawing (75.9%) and of subsequent anneal (64 hours at 800° C.) on hydrogen absorption and C_s; wire stock immersed in N H_2SO_4 at 35° C. (1 cc NTP per gram = 0.00899% H.)

of Fick's equation (for similarly shaped specimens) is of such nature that the concentration of hydrogen at any given point (and hence the ratio of total hydrogen to the limiting amount) is a function Dt/a^2 where a is a linear dimension of the steel (for example, a may be taken as the radius of a sphere or cylinder or the thickness of a slab or sheet). For the case of the cylinder (of great length compared to radius) and the slab (of great width and length compared to thickness), D being considered constant, values of the ratio of total hydrogen absorbed to the final limiting amount are shown in Figure 19 as a function of $\sqrt{Dt/a^2}$ (which is chosen as abscissa instead of Dt/a^2 in order that the slope of the curve at the origin be finite). This figure applies only to the case of constant D.

From this type of relation it is clear that the time required for a specimen to absorb half the total amount of hydrogen (independent of the total) would be proportional to the square of the dimension a—i.e. it would be expected to take four times as long to half-saturate a half-inch rod as it would to half-saturate a quarter-inch rod. Moreover, in the case of constant diffusivity, the reverse process (i.e. removal of hydrogen from the saturated specimen) would be expected to be identically similar in the sense that the time required for the removal of any given percentage of the limiting amount of hydrogen should be the same as that required for the absorption of the same percentage by the same specimen.

From the present investigation, however, it appears that the evolution rate is always slower than the absorption rate—i.e. the time required for a specimen to lose half its hydrogen is always considerably greater than that required to absorb one-half. Moreover, for a given specimen this half time is greater, the smaller the total amount of hydrogen (i.e. the weaker the acid in which it is immersed). In view of these facts, it is clear that the assumption of a constant diffusivity independent of hydrogen content is inadequate. Yet the small total percentage of hydrogen leads to a reasonably strong presupposition that the "true" diffusivity should be independent of variation of hydrogen content; the maximum observed was about 0.5 cc (NTP) per gram iron which corresponds to only one hydrogen atom to 400 iron atoms. Since diffusivity does not commonly change much in the region 0-0.25 atomic percent, it seems reasonable

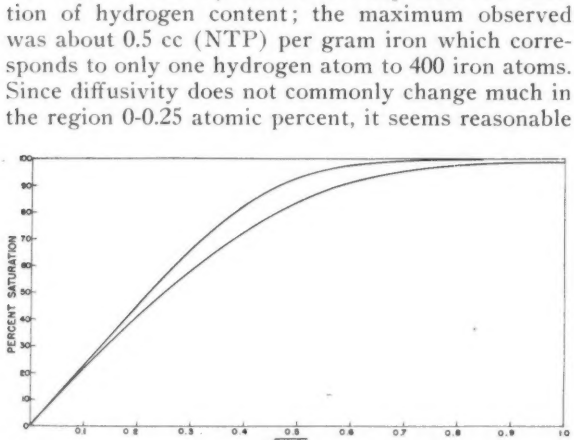


Figure 19—Relation, in ideal case, of constant diffusivity (D), between percentage saturation of diffusing substance and time (t) expressed in terms of: Square root of Dt/a^2, where a is thickness of slab (upper curve) or radius of cylinder (lower curve).

to postulate that the observed variation does not correspond to a change of the diffusivity of lattice-dissolved hydrogen atoms in a perfect iron lattice, but rather that the change is occasioned by a "trapping" of a fraction of the hydrogen atoms in "imperfections" of the iron lattice. It might be thought that the observed phenomena could be accounted for by the supposition that gaseous hydrogen, at high pressure, accumulates in voids of macroscopic size. If this were the case, the amount so accumulated would be proportional to the square of the concentration of lattice-dissolved hydrogen (Sievert's law) hence the amount in the voids would be a negligibly small fraction of the total hydrogen at low concentrations, and the diffusivity would be greater than at higher concentration. This is contrary to observation, which indicates definitely that the diffusivity is greater at higher concentrations than at lower.

This conclusion (that a large part of the hydrogen is somehow trapped) is strengthened by the observed large increase of absorbed hydrogen occasioned by prior cold work. If this tentative hypothesis is correct, then the diffusion of hydrogen into steel is somewhat analagous (mathematically) to the diffusion of oxygen into copper containing a small amount of silicon. The true solubility of oxygen in copper is small, yet the total amount of oxygen "absorbed" by the alloy—and held principally as SiO_2—may be much larger. The time required for saturation with oxygen is much longer than if no silicon were present, because so much more oxygen must diffuse, and the reverse process would require an impracticably long time as SiO_2 is very stable and would give up its oxygen very slowly. The analogy of this case to that of hydrogen in steel is quite pronounced—the imperfections (of unknown nature) in the iron lattice being the analogue of the silicon atoms in copper; the affinity of these imperfections for hydrogen is considerably less than that of silicon for oxygen since hydrogen is evolved at a finite rate.

If this view is correct, the approximate mathematical treatment previously developed for "subscale"* may be used. On this basis, the time required for a long cylinder to absorb one half the total amount of hydrogen, called the half-time $t_{1/2}$, is given approximately by the expression

$$\frac{D_o t_{1/2}}{a^2} = \frac{1}{32}\,\frac{C_S}{C_o}$$

where C_S is the total (observed) solubility of hydrogen, C_o is the lattice solubility and a is again the radius. The same formula applies to the sheet or slab, a being then interpreted as the thickness. It will be noticed that if the total solubility equals the lattice solubility, $Dt_{1/2}/a^2 = 0.068$—i.e. the above formula is valid only if C_S/C_o is considerably larger than unity.**

$$Dt_{1/2}/a^2 = 0.034\,\frac{C_S}{C_o}\left(\frac{1}{1-\tfrac{1}{2}\,\frac{C_o}{C_S}}\right)$$

An important feature of the above formula is that

* The mathematical analysis of these phenomena is given as an appendix. It is based in part on an earlier paper. L. S. Darken—Diffusion in Metal Accompanied by Phase Change.[3] Trans. AIME 150 157 (1942).

** For intermediate cases (i.e. if C_S/C_o is slightly greater than unity) the above formula may be used.

the half-time is again found proportional to a^2. From the mathematical derivation, morever, the amount absorbed should be proportional to the square root of the time, provided the boundary condition is maintained constant and dimensions do not change appreciably. Accordingly, a plot of the measured amount of hydrogen absorbed against the square root of time should be a nearly straight line. Actually the curves are nearly straight over their entire length until saturation is reached. Thus it is convenient to define a saturation time t_s as the time at which the straight line (extended) passes through the saturation value, then:

$$\frac{D_o t_s}{a^2} = \frac{1}{8}\frac{C_s}{C_o}$$

Note there is a relationship between permeability and diffusivity. If the hydrogen were all dissolved in the lattice, and if the diffusivity were constant, this relation would be $P = 10\rho D(C_1 - C_2)$ where C_1 and C_2 are the concentrations of hydrogen on the ingoing and outgoing sides respectively and ρ is the density of the steel (the factor 10 occurs since the permeability was defined in terms of a diaphragm 0.1 cm. thick). The above conditions are by no means fulfilled in the cases investigated. On the basis of the previously described assumptions (and using the same symbolism) $P = 10\rho D_o C_o$ it being further assumed that the concentration of hydrogen on the outgoing side of the diaphragm is negligibly small compared to that on the ingoing side i.e. that the outgoing surface presents no significant resistance to the passage of hydrogen. This formula provides a means of comparison of the two types of measurements since P is directly determined from the permeability (diaphragm) experiments, and D_oC_o is determinable from experiments of non-stationary state type with cylinders or slabs, by means described in the appendix. In fact, if the amount of hydrogen absorbed by a cylinder or slab is plotted against the square root of time, the resultant curve is found to be a straight line over an appreciable distance. If the slope of this line is designated λ, then $D_oC_o = \frac{\lambda^2 a^2}{8C_s}$ (valid when C_s is large compared to C_o).

In order to compare the permeability as found by the direct and indirect methods, both types of measurements were made on discs cut from 2-inch diameter cold rolled SAE 1020 steel bar. The permeability found by the direct method at 35° C., varied from 5.0 to 6.9×10^{-6} and averaged 6.0×10^{-6}. The indirect measurement was made by total immersion of similar discs in molal citric acid at 35° C. for various times with results shown graphically in Figure 5 (upper line). The permeability found by use of these data and the foregoing equations* is 6.8×10^{-6} in reasonably good agreement with the directly measured value. This agreement is regarded as a substantiation of the postulates and reasoning upon which the formulas are based.

It is also possible in principle to obtain D_oC_o from initial measurements (i.e. measurements before steady state is obtained) of the rate of transmission of hydrogen through a diaphragm. In general the plot of diffused hydrogen versus time shows an induction period during which the rate rises from zero to the steady state value. By extrapolation backwards of the linear portion it is possible to obtain a "time intercept" designated t°, from which D_oC_o is given by the approximate expression

$$D_oC_o = \frac{a^2C_s}{2t^\circ}$$

This relation was not found to be particularly fruitful as t° was difficult to determine with precision; even a slight departure from linearity in the later portion of the curve leads to a prohibitively wide choice of extrapolations, and erratic behavior at the beginning gives rise to a large error in t°. Nevertheless (if D_o, C_o, and C_s are known) the above relation may be used to approximate the time which will elapse between the immersion of one side of a diaphragm in acid and the transmission of hydrogen from the other side, or to estimate the "depth" of penetration of hydrogen at any time.

Since in any diffusion problem the boundary conditions are of great importance, it was deemed advisable to have some measure of the potential of hydrogen at least on the acid side of the specimens. By potential is meant the "driving force"; this is usually expressed in terms of pressure or concentration. In general, the rate of passage of gas through a diaphragm is greater the greater the pressure on the input side. If the gas dissolves as molecules in the diaphragm material, the rate is usually proportional to the pressure, at least for pressures sufficiently low that the ideal gas laws are obeyed. Because gases dissolve not as molecules but rather as atoms in metals, the rate would be expected to be proportional to the square root of the pressure; this is well established for hydrogen in iron at elevated temperatures.[2]

In the present experiments (acid immersion) no actual gage pressure (above atmospheric) of H_2 gas is developed on the surface of the specimen; hence the pressure concept, if adopted, must be regarded as a virtual pressure (which could perhaps be realized as a true pressure within small cavities in the specimen). Because no equilibrium gage pressure has been measured in this series of experiments (or in any other similar experiments, to the best knowledge of the authors) it seems best to drop pressure and to employ the term "fugacity," a thermodynamic quantity which may be regarded as a potential or vitual pressure but only for an ideal gas. By aid of the assumption that the observed electrical potential of steel immersed in acid is a measure of hydrogen overvoltage, the fugacity of hydrogen at this surface can be determined by measurement of the electrical potential of the specimen versus a hydrogen electrode at one atmosphere pressure) in the same solution. The relation is

$$E = \frac{2.303\,RT}{F} \log f_{H_2}^{1/2}$$

E being electrical potential in volts, R gas constant,

* Actually the slope of the linear portion in Figure 5 was divided by the ratio of the total area to that of the two faces (1.22) to give λ, since in this case the thickness was not negligible in comparison to the diameter as assumed in deriving the formulas.

T absolute temperature, F the Faraday equivalent, and f_{H_2} the fugacity of hydrogen (in atmospheres). At 35° C. the value of $\frac{2.303\,RT}{F}$ is 0.0611 volts.

As the measured E in a sulfuric acid solution is frequently about 0.25 volt, it follows that the fugacity of hydrogen thus calculated is of the order 10^8 atmospheres. This is so astonishingly high (far above the bursting point of steel) that suspicion is immediately cast on the above assumption that the measured potential is that of the hydrogen overvoltage. Certainly the measured potential is not even remotely related to the reversible potential of an iron electrode, for it is unaffected by concentration of Fe^{++} ions in the solution; but it is sensitive to pH. Nevertheless, because the specimen is rather rapidly dissolving during the measurement, and the system is obviously not at equilibrium with respect to the reaction $Fe + 2H \rightarrow H_2\,(g) + Fe^{++}$, it is quite possible that it is improper to employ the foregoing equilibrium equation to calculate f from E. On the other hand, it is at least possible that the system is at or near equilibrium with respect to the reaction

$$H^+ \text{ (aq. soln.)} + \varepsilon \rightleftarrows H \text{ (dissolved in steel)}$$
$$\text{or } H^+ \text{ (aq. soln.)} \rightleftarrows H^+ \text{ (dissolved in steel)}$$

in which case the equation is applicable.

The order of magnitude of the fugacity (f) of hydrogen in the specimen may be estimated in other ways. From the directly measured solubility of hydrogen in iron at elevated temperatures,[4] its solubility at 1 atmosphere and 35° C. may be estimated by extrapolation to be 10^{-5} to 10^{-6} cc (NTP) H_2 per gram iron.* In the case of specimens immersed in acid, the amount of lattice-dissolved hydrogen (to which Sievert's law applies) as distinguished from total hydrogen is not certain, but it may be taken as being of the order of the lowest observed total hydrogen about 10^{-2} cc H_2 per gram Fe. The fugacity thus calculated, since solubility is proportional to $f^{1/2}$, is again of the order of 10^6 to 10^8 atmospheres.

The fugacity may be estimated independently in a third manner by a similar comparison of the permeability, as extrapolated from measurements at high temperature, with that observed in this investigation. As the result of experiments at temperatures from 245-779° C. Smithells and Ransley[2] give the following equation for the permeability of hydrogen through iron

$$P = 0.049\, f^{1/2}\, e^{-4800/T}$$
$$\log P = -1.36 - \frac{2085}{T} + \log f^{1/2}$$

Inserting the highest observed permeability at 35° C. namely 10^{-5}, we find that the fugacity is 10^6 atmospheres. If credence is placed in the measurements of Ham which indicate smaller values of permeability at lower temperatures, then the calculated fugacity is higher (10^7 to 10^8 atmospheres).

All of these independent methods give roughly similar values for the fugacity of hydrogen in iron immersed in normal sulfuric acid, and we conclude that this fugacity does lie between 10^6 and 10^8 atmospheres (and probably nearer the higher value) and that the electrical potential of the specimen is at least a rough indication of the hydrogen overvoltage. It should be noted that the above uncertainty of a factor of 100 in the fugacity (10^6 to 10^8 atmospheres) corresponds to only 0.06 volt in the measured potential (about 0.25 volt).

It might be mentioned at this point that from the standard electrode potential of iron (0.441 volt) it follows that the limiting fugacity of hydrogen which may be developed in a sealed vessel by reaction of iron with a normal acid solution also normal with respect to Fe^{++} is 10^{14} atmospheres.

The foregoing discussion deals with the ability of various steels to absorb hydrogen rather than the actual hydrogen content of commercial steel (which is usually much less than amounts introduced by our procedure). It is felt there are two distinct aspects of the hydrogen problem: 1) characteristics of the steel itself as indicated by ability to absorb and transmit hydrogen, and 2) the effect of actual hydrogen content. This report deals only with the first aspect; this fact is not to be interpreted as a disparagement of the second aspect, which is now well recognized as being of great importance.

Summary

Principal findings of the present investigation in regard to the amount of hydrogen absorbed by steels during acid pickling are:

1. The amount absorbed is related to the dimensions in the manner to be expected from the usual diffusion laws.
2. The amount absorbed increases linearly (or essentially so) with square root of time until a limiting amount is absorbed: after this saturation value is reached, no further hydrogen is absorbed at longer times.
3. This saturation value is very small for hot rolled steel but increases markedly with cold work; the extent of this increase varies from steel to steel.
4. The saturation value is decreased slightly by long time annealing of cold worked steel, but the rate of absorption is decreased considerably by such anneal.
5. The effect of lowering acidity (increasing pH) is small on the saturation value, but more pronounced on the rate of absorption.

References

1. Bardenheuer and Thanheiser, *Mitt. Kaiser Wilhelm Inst. fur Eisen.* **10,** 323 (1929).
2. Smithells and Ransley, *Proc. Roy. Soc.* **150,** 172 (1935).
3. L. S. Darken, *Trans. AIME* **150,** 157 (1942).
4. M. H. Armbruster, *J. Amer. Chem. Soc.* **65,** 1043 (1943).

APPENDIX

Part I—Diffusion of Hydrogen from a Plane Surface into Steel. [This derivation is amplified from "Diffusion in Metal Accompanied by Phase Change," L. S. Darken, Trans. AIME **150,** 157 (1942)].

It is assumed that hydrogen has a relatively small solubility in the ferrite lattice, but that a relatively large amount of hydrogen may be absorbed—the excess over the lattice solubility being localized at "dislocations" or at other disturb-

* This estimate of lattice solubility (C_o) is in agreement with that estimated from the extrapolated value of the diffusivity ($D = 10^{-5}$) and the measured value of D_oC_o (about 10^{-7}). The extrapolated value is obtained from the equation $\log D = \frac{525}{T} - 3.04$ which satisfied the available measurements from 400-900° C.

ances of, or departures, from the ideal lattice. It is also assumed that the amount of hydrogen held by these dislocations is independent of the amount in true solid solution—an approximation valid only when the total amount of hydrogen is relatively large. It is further assumed that the concentration of lattice dissolved hydrogen is so small that its diffusivity may be regarded as independent of concentration.

On these assumptions, when hydrogen penetrates a large plane surface into a thick uniform body of steel initially devoid of hydrogen, the solution of the equation representing Fick's law*

$$\frac{\partial C_o}{\partial t} = D_o \frac{\partial^2 C_o}{\partial x^2} \qquad \text{I.1}$$

may be written

$$C_o = C_o^\circ + B\int_o^{X/(2\sqrt{D_o t})} e^{-S^2} dS \qquad \text{I.2}$$

where the symbols have the following significance:

C_o — Concentration of lattice-dissolved hydrogen at any point
C_o° — Concentration of lattice-dissolved hydrogen at surface
C_m — Mean concentration of hydrogen in region penetrated
t — Time
D_o — Diffusivity of lattice-dissolved hydrogen
x — Distance from plane surface
S — Integration variable
B — Integration constant
X — Thickness of region penetrated by hydrogen

By equating the amount of hydrogen entering the metal to the amount accumulating, thus,

$$-D_o\left(\frac{\partial C_o}{\partial x}\right)_{x=o} = C_m \frac{dX}{dt} \qquad \text{I.3}$$

and substituting therein the value of the partial derivative obtained by differentiation of I.2, an ordinary differential equation is obtained

$$-\frac{BD_o}{2\sqrt{D_o t}} = C_m \frac{dX}{dt} \qquad \text{I.4}$$

the solution of which is

$$X = \alpha\sqrt{t} \qquad \text{I.5}$$

where α is a parameter describing the rate of penetration; B is found to have the value

$$B = -\alpha C_m/\sqrt{D_o} \qquad \text{I.6}$$

It is now possible to evaluate α in terms of D_o by substituting I.5 and I.6 into I.2 at $x = X$ and $C_o = 0$ (strictly C_o negligibly small).

$$O = C_o^\circ - \frac{\alpha C_m}{\sqrt{D_o}}\int_o^{\alpha/(2\sqrt{D_o})} e^{-S^2} dS \qquad \text{I.7}$$

By expanding the integral into a series and rearranging terms it is found that

$$\alpha = 2\sqrt{\frac{C_o^\circ D_o}{2C_m}}\left(1 + \frac{C_o^\circ}{12C_m} - \frac{C_o^{\bullet}}{240C_m^2} + \ldots\right) \qquad \text{I.8}$$

Usually C_o°/C_m is small; in such cases the term in parenthesis is essentially unity and may be omittted; then

$$\alpha = \sqrt{\frac{2D_o C_o^\circ}{C_m}} \qquad \text{I.9}$$

Thus to a good degree of approximation the rate of penetration of hydrogen $\left(\frac{dx}{dt} = \frac{1}{2}\alpha/\sqrt{t}\right)$ is directly proportional to the square root of the lattice diffusivity and to the square root of the ratio of the lattice concentration of hydrogen at the surface to the mean (total) concentration in the penetrated region.

Part II—Hydrogen Absorption by Slab or Sheet (of Great Length and Breadth Compared to Thickness) and Cylinder (of Great Length Compared to Diameter).

Using the same assumptions and symbolisms as in Part I, and designating the thickness of the slab or sheet by a and the average (or apparent) concentration by C, we write from I.9

$$\frac{dX}{dt^{1/2}} = \sqrt{\frac{2D_o C_o^\circ}{C_m}} \qquad \text{II.1}$$

and from the fact that the average concentration C is proportional to the depth of penetration (being C_m at a/2)

$$X = \frac{a}{2}\frac{C}{C_m} \qquad \text{II.2}$$

Eliminating X between these two equations

$$C = \frac{2(D_o t)^{1/2}}{a}\sqrt{2C_o^\circ C_m} \qquad \text{II.3}$$

It is convenient to plot C vs. $t^{1/2}$. Such a plot (up to the time of saturation) is seen to be linear and its slope ($dC/dt^{1/2}$) is designated λ. Substituting this in II.3 gives

$$D_o C_o^\circ = \frac{\lambda^2 a^2}{8C_m} \qquad \text{II.4}$$

This is the relation used in the text for calculating the permeability $P = 10\rho D_o C_o^\circ$ where ρ is the density. The superscript is omitted in the text as there the only lattice concentration considered is at saturation when $C_o = C_o^\circ$. Similarly at saturation $C = C_s = C_m + 1/2\ C_o^\circ$; as C_o° is small C_s is written as an approximation in the text where C_m occurs in II.4.

In the case of the cylinder it is readily seen that II.1 is still approximately valid providing the depth of penetration is small compared to the radius; i.e. if attention is restricted to the beginning of the process. Similarly II.2 is approximately true under the same restriction if a is interpreted as the radius in this case. This may be demonstrated as follows. If X be small, then the fraction of a cross section penetrated is $\frac{2\pi\tau X}{\pi\tau^2} = \frac{2X}{\tau}$ and the fraction of complete saturation is C/C_m; equating these two, $X = \frac{\tau}{2}\frac{C}{C_m}$ which is seen to be identical with II.2 if $a = \tau$.

In view of the fact that, in this appendix, C_o° is assumed to be small compared to C_s, whereas in some of the cases investigated experimentally, this assumption is questionable, it is desirable to inquire as to the magnitude of the error introduced thereby in cases where C_o° is nearly equal to C_s. Let us now investigate the error in II.3 when $C_s = C_o^\circ$, in accord with approximations used in deriving this equation, C_m then equals 1/2 C_s; II.3 then becomes

$$C/C_s = 2(Dt)^{1/2}/a$$

and at 50 percent saturation $\left(\text{i.e. when } \frac{C}{C_s} = \frac{1}{2}\right)$, $2(Dt)^{1/2}/a = 1/2$ or $(Dt)^{1/2}/a = 1/4$. The exact treatment of this case (Andrews and Johnston—J. Am. Chem. Soc. **46**, 640, (1924) gives, at 50 percent saturation $(Dt)^{1/2}/a = 0.222$. The error involved in II.3 is thus not excessively large even in this extreme case, and it becomes much smaller as the ratio of C_s to C_o° increases.

Another check on the magnitude of error involved when $C_o^\circ \cong C_s$ is obtained by comparing the time intercept for permeability measurement as calculated from the above with that calculated by exact treatment. From I.5 and I.9 the distance of hydrogen penetration at time t is

$$X = \sqrt{2D_o C_o^\circ t/C_m}$$

or the time required for complete penetration (from one side) of a slab or sheet of thickness a is $\frac{a^2 C_m}{2D_o C_o^\circ}$. Again if $C_o^\circ = C_s$ then $C_m = 1/2C_s$ and the time is $\frac{a^2}{4D}$. The exact treatment of this case (R. M. Barrer—"Diffusion in and Through Solids," The Macmillan Co., 1941) gives this time (or more strictly the intercept on the time axis of the linear part of the curve) as $\frac{a^2}{6D}$. Again the error in the equations developed

* Fick's law is a purely formal law stating (in this case) that the hydrogen which enters an elementary volume either leave that volume or stays there. As diffusion occurs only in the regions where the dislocations are "filled," these latter behave simply as inert material (according to the assumptions stated) so that the law may be applied to lattice dissolved hydrogen as above. Strictly, the solution given in I.2 has a limited region of validity.

here is not excessively large considering the flagrant violation here of the assumptions used in developing them. The error is much smaller when C_s/C_o° is larger.

Part III—Comparison of Initial Absorption and Evolution Rates.

Using the same assumptions and symbolism as in Parts I and II except that λ is now subscripted λ_i to indicate that it characterizes an ingoing (or absorption) rate and λ_o is used to characterize the corresponding initial outgoing (or evolution) rate. Y is used to designate the distance partially depleted of lattice dissolved hydrogen. From II.4

$$\lambda_i = \sqrt{8C_mC_o^\circ D_o/a} \qquad \text{III.1}$$

It is now necessary to distinguish between C_m, the mean concentration of hydrogen in the penetrated region (while penetration is progressing) and C_s, the ultimate steady state hydrogen concentration. These are approximately connected (under the assumptions previously stated) by the relation

$$C_m + \tfrac{1}{2}C_o^\circ = C_s \qquad \text{III.2}$$

By means of this relation C_m may be eliminated from III.1.

$$\lambda_i = \sqrt{8}(C_s - \tfrac{1}{2}C_o^\circ)\, C_o^\circ D_o/a \qquad \text{III.3}$$

It is also convenient to use the fraction F, $\left(\equiv \frac{\frac{1}{2}C_o^\circ}{C_s}\right)$ which, it will be noted, is one minus the ratio of the steady state hydrogen content of a slab or sheet exposed to acid on one side only to that of a similar slab or sheet exposed to acid on both sides.

$$\lambda_i = \sqrt{8C_sC_o^\circ D_o(1-F)/a} \qquad \text{III.4}$$

In order to calculate (approximately) λ_o for the initial outgoing rate we equate the rate of loss determined from the gradient at the surface $\left(D_o \frac{C_o^\circ}{Y}\right)$ to that from total hydrogen content $\left(\frac{1}{2}C_o^\circ \frac{dY}{dt} = FC_s \frac{dY}{dt}\right)$ [The expressions are cruder approximations than the corresponding ones in the case of absorption.]

$$D_oC_o^\circ/Y = FC_s \frac{dY}{dt} \quad \text{III.5 or } Y = \sqrt{2D_oC_o^\circ t/FC_s} \qquad \text{III.6}$$

Also, initially the distance Y is proportional to the decrease in the average concentration i.e. to $(C_s - C)$ being a/2 when $(C_s - C)$ is $\frac{1}{2}C_o^\circ$ $(=FC_s)$

$$Y = \frac{a}{2} \frac{C_s - C}{FC_s} \qquad \text{III.7}$$

Equating these two expressions (III.6 and III.7) for Y

$$C_s - C = \frac{2FC_s}{a}\sqrt{\frac{2D_oC_o^\circ t}{FC_s}} = \sqrt{8C_sC_o^\circ D_oFt}/a \qquad \text{III.8}$$

$$\text{and } \lambda_o = -\frac{dC}{dt^{1/2}} = \sqrt{8C_sC_o^\circ D_oF}/a \qquad \text{III.9}$$

Comparing III.8 with III.4 the ratio

$$\lambda_i/\lambda_o = \sqrt{(1-F)/F} \qquad \text{III.10}$$

Also inserting the definition F

$$\lambda_i/\lambda_o = \sqrt{(2C_s - C_o^\circ)/C_o^\circ} \qquad \text{III.11}$$

Since the assumption that the dislocations in any region are either all occupied (by hydrogen) or all empty is an oversimplification, it seems reasonable to expect III.10 to be a better approximation than III.11; F is to be interpreted as noted previously in this section.

DISCUSSION

*By Dr. M. A. Scheil**

In the presentation it was noted that the amount of hydrogen solubility varied a great deal for hot rolled steel. Have the authors found any reason for this observation in the chemical composition or deoxidation practice used for the particular steels they have studied?

* Director, Metallurgical Research, A. O. Smith Corp., Milwaukee, Wis.

*By W. B. Sullivan**

Have comparative studies been made of any other types of materials, such as straight chromium types covering ranges from about 5 percent to 12 percent chrome, with very small traces of nickel, or the austenitic grades beginning with the 18-8 group?

* Lebanon Steel Foundry, Lebanon, Penn.

Authors' Reply

So far we have investigated only the behavior of hydrogen in plain carbon steels and not in the alloys mentioned by Mr. Sullivan.

As noted by Dr. Scheil, we did find that the observed solubility of hydrogen in hot rolled steel varied somewhat. However, this variation was very small compared to that occasioned by cold work. In fact the magnitude of the solubility of hydrogen in hot rolled steel was not much greater than that of the experimental error in many cases. Hence we hesitate to place any interpretation upon the slight variations found.

Prior literature contains many reports, such as those of Zapfe and coworkers, of the effects of hydrogen on the mechanical properties of steels. However, it contains very little quantitative information as to the actual rate and amount of hydrogen absorption. It was intended that the present paper should fill this gap partially.

Cathodic Protection Applied to Gas and Electric Utility Operations*

By WILLIAM J. SCHREINER

THE PREVENTION of damage to its underground structures, arising from corrosion and electrolysis, is a serious and difficult problem for public utilities in a metropolitan area.

The Cincinnati Gas and Electric Company serves 311,087 customers with electricity in 287 communities having an aggregate population of 950,000 persons. It serves 239,346 customers with gas in 56 communities, with an aggregate population of 750,000. It serves 8313 customers with water in three communities, with an aggregate population of 65,000 people. This system requires 210 miles of high voltage, underground cables, 76 miles of gas transmission lines, 1576 miles of gas distribution mains, and 50 miles of water mains. The underground plant represents an investment of $15,000,000, which is continuously endangered by corrosion and electrolysis.

The danger to underground cable sheaths is mainly from stray current electrolysis, source being leakage from street railway circuits, or d-c Edison systems. There are also cases of lead sheath failure due to soil and chemical corrosion. Cathodic protection is applicable to the underground cable sheaths to mitigate this corrosion problem. It is more suitable than the use of drainage circuits because of the difficulty of locating the source of the stray currents.

WILLIAM J. SCHREINER

Presently Gas Engineer with the Cincinnati Gas & Electric Company, Cincinnati, Ohio, responsible for corrosion and electrolysis work. He is an electrical engineering graduate of the University of Cincinnati, a graduate of the safety engineering course, New York University, and a registered mechanical engineer. His experience includes 15 years in gas and water system construction and operation, five years in manufacture and installation of gas and steam equipment and four years service with army ordnance developing high pressure hydrogen plants.

Power Cable Protection

An example of cathodic protection applied to underground cables is the case of a 66kv, 60,000 kva, oil-filled cable between the West End of Cincinnati and Oakley, a suburb to the east. The location of this cable is shown in Figure 1. When it was installed in 1937 a survey of sheath potentials to ground was made along the cable. No dangerous potentials were revealed, although the peculiar vulnerability of single-conductor cables to electrolysis was realized. Sheath bonding transformers were installed to limit a-c potentials to 15 volts with full load on the circuit. Later experience showed that even a very small d-c potential, superimposed on lead sheath subject to a-c potentials, causes serious electrolysis troubles.

In 1944, street railway stray currents of small magnitude began to cause trouble to the cable sheath in the congested, downtown area. Preliminary tests showed current requirements of 7 amperes, at 6 volts, between the cable sheaths and car rails, to make the sheaths .26 volts negative within the area. On this basis, a 115-volt, single phase, 60 cycle a-c; 10 volts, 10 ampere, d-c copper-oxide rectifier was installed at 3rd and John Street. The 66kv cable sheaths were made negative with respect to earth, when the unit delivered 6 amperes, at 4.5 volts d-c.

In 1946, it appeared the sheath potential of the 66 kv cable was appreciably lower than that of a Western Union cable in the same area. This made it desirable to install a second rectifier between the Western Union cable and the car rails, to keep the cable sheaths at the same potential. The Western Union cable also was bonded to a 4 kv cable in the area. Car rail joints in the neighborhood of the rectifiers were tested and bonded for better anode current distribution. Zero potentials between cable

★ Paper presented at the annual NACE meeting in St. Louis, Mo., April 5-8, 1948.

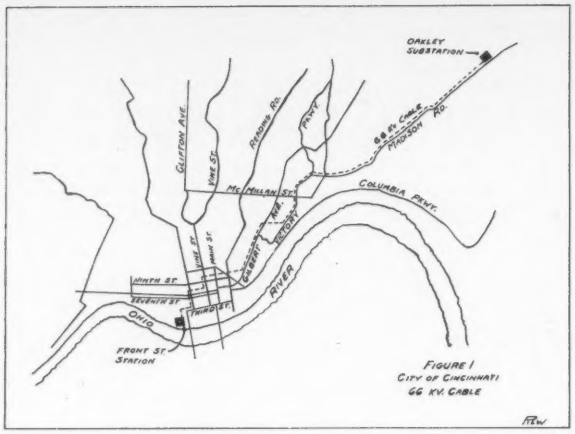


FIGURE 1
CITY OF CINCINNATI
66 KV. CABLE

sheaths, and maintenance of the 66 kv sheath negative to earth, were obtained with the following rectifier operation:

Reading	66 kv Cable Rectifier	Western Union Cable Rectifier
d-c volts	4.5	4.0
d-c amperes	6.0	12.0

In the fall of 1945, oil was lost from the 66 kv cable in the eastern part of the circuit, and it became necessary to replace a section between manholes 20 and 21. A potential survey of the entire circuit with respect to water mains was made, as shown in Figure 2. Since the area of greatest positive potential corresponded with the trouble zone, it was decided to install cathodic protection at this location. A rectifier

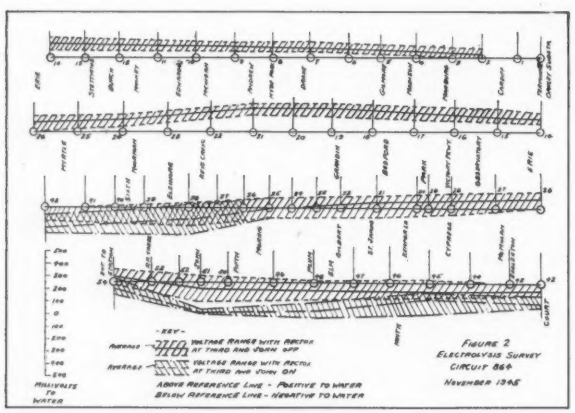


FIGURE 2
ELECTROLYSIS SURVEY
CIRCUIT 864
NOVEMBER 1945

TABLE I

LOCATION	Ground	Max.	Min.	Average 24 Hours
Third & John	Fire Plug	—1.20	— .80	—1.046
Race & Shillito	Fire Plug	— .76	— .52	— .663
Court & Gilbert	Fire Plug	— .52	— .26	— .503
Gilbert & Eden Pk. Entr.	Fire Plug	— .52	— .28	— .387
Victory Pkwy. & McMillan	Fire Plug	— .54	— .40	— .520
Madison & Annwood	Fire Plug	—1.10	— .90	— .917
Madison & Observatory	Fire Plug	— .96	— .72	— .853
Brotherton & Gibbon	Fire Plug	— .072	— .032	— .0549
Third & John	Lead Plate	— .64	— .48	— .557
Race & Shillito	Lead Plate	— .64	— .40	— .524
Court & Gilbert	Lead Plate	— .26	— .08	— .186
Gilbert & Eden Pk. Entr.	Lead Plate	— .32	— .20	— .267
Victory Pkwy. & McMillan	Lead Plate	— .32	— .20	— .260
Madison & Annwood	Lead Plate	— .80	— .68	— .725
Madison & Observatory	Lead Plate	— .52	— .44	— .497
Brotherton & Gibbon	Lead Plate	+ .05	+ .02	+ .032

unit was connected between the grounded neutral of the sheath bonding transformers and the water main. A supply of 12 amperes at 2.0 volts d-c furnished satisfactorily negative sheath-to-ground and sheath-to-water main potentials over the entire cable. A typical survey is shown in Table I.

Gas Line Protection

An example of cathodic protection as applied to gas transmission lines is the case of the 18-inch natural gas line between Centerville, Ohio, and Norwood, Ohio. The location of this line is shown in Figure 3.

Average age of the line is 40 years. It is bare and joined with mechanical couplings. It is an important link in the transmission system supplying Cincinnati and municipalities to the north. A record of leaks on this line is shown in Figure 4. There is a definite indication of two areas of trouble, one between Franklin and Middletown, and the other in the neighborhood of Huntsville. The first and most troublesome area, between U. S. Highway No. 25, station 41,768, and the Blue Ball Pike, station 56,199, was selected for further investigation and protection.

To confirm the corrosive areas shown by the leak record, a soil survey was made to obtain actual indications of corrosivity. The usual criterion of the corrosivity of soil is its resistivity, and apparatus based on such measurements were available. The currents that accompany corrosion, however, depend not only on the resistivity of the soil, but also on the potential of the metal with respect to the adjacent electrolyte, and on the limitation of the corrosion currents by polarization films and corrosion products. To take account of all the factors affecting the corrosion currents, it was decided to use the Columbia Rod to measure corrosivity. Such a rod is shown in Figure 5. It consists essentially of a 1¼ inch hollow steel tube, approximately 5 feet long, the tapered point being constructed of two dissimilar metals, copper and steel, electrically insulated from each other. Lead wires are attached to the dissimilar metals, and are connected to a microammeter. In field observations, a hole is made first to pipeline depth with a soil auger. The Columbia Rod is inserted in the hole. The galvanic current generated by the dissimilar metals, with the soil acting as an electrolyte, is then observed and recorded. Research and previous experience indicate 1000 microamperes to be the line of demarkation between seriously corrosive and mildly corrosive soils. Survey results are plotted in Figure 6.

Since the corrosive nature of the soil substantiated the leak repair experience, it was decided to apply cathodic protection to the section in which the worst conditions were found. Availability of electrical energy made it possible to use two rectifiers for protection. Property rights, and the presence of an underground telephone cable, limited anode locations to within about 500 feet of the pipe line, as shown in Figure 7 and Figure 8.

The line was bonded completely between the insulating, sectionalizing couplings by welding pipe-coupling shunts across each joint, with connections

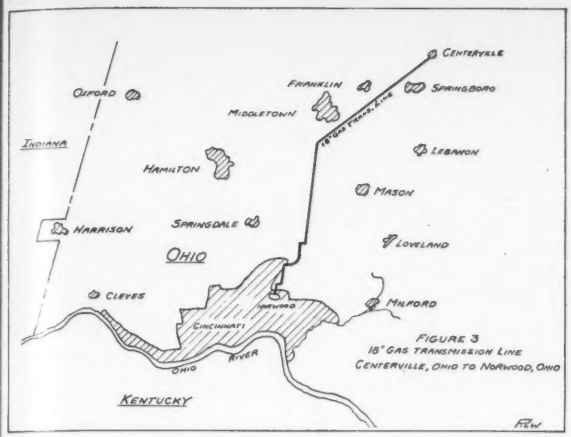
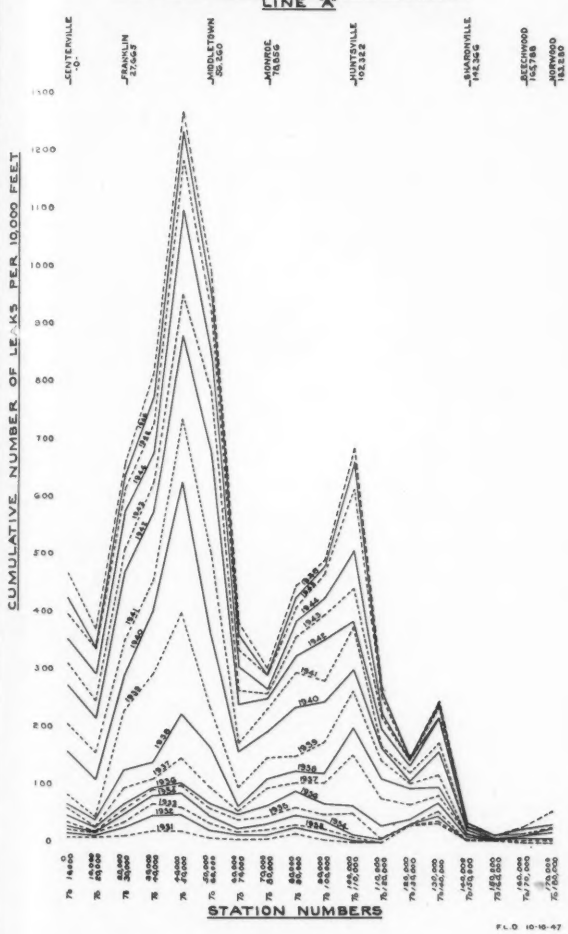


FIGURE 3
18" GAS TRANSMISSION LINE
CENTERVILLE, OHIO TO NORWOOD, OHIO

FIGURE 4
CUMULATIVE LEAK DENSITY BY YEARS
IN 10,000 FOOT SECTIONS OF 18" PIPE LINE
LINE "A"



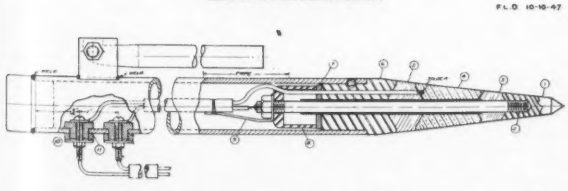


Figure 5—Columbia Rod, for determining soil corrosivity. (Legend for numerals unavailable.)

to the center rings. The couplings were located by applying a d-c potential to a section of the line with a welding generator and a long lead, and noting the increased voltage drops whenever couplings were encountered.

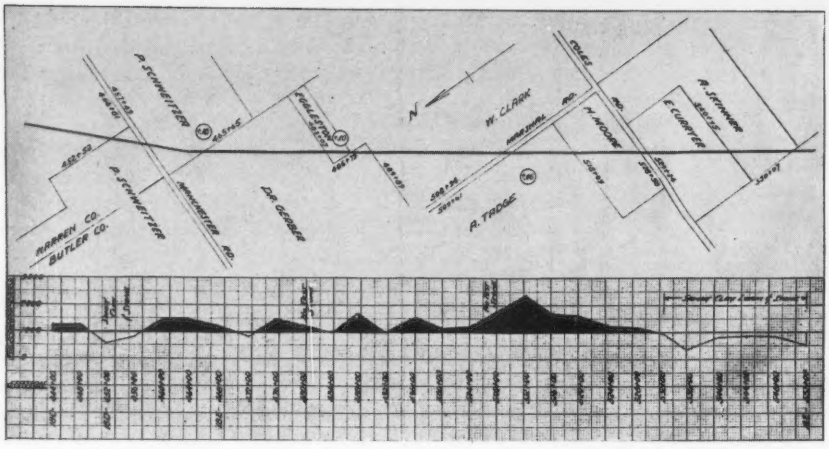
Cathodic protection design consisted essentially of determining current requirements. By using a temporary ground bed, and a welding generator as a source of energy, currents of different values were impressed on the pipe.

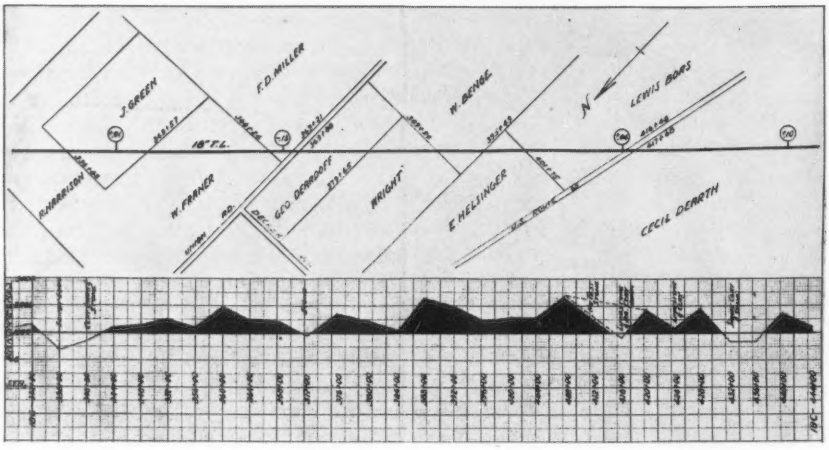
Current values, and the corresponding pipe-to-copper sulphate electrode potentials were measured. These values were plotted on logarithmic paper, with currents as abscissae. Actual requirements were determined on the theory that when the current becomes sufficient to prevent corrosion, the cathode will act as a hydrogen electrode, whose potential varies linearly with the logarithm of the current flowing to it. The joint of intersection of the projections of the straight lines indicates the current required to prevent corrosion, as shown in Figure 9. The preliminary investigations gave a circuit resistance of 3.3 ohms, with the use of a temporary anode; 75 volts d-c impressed, and 22 amperes d-c flowing. The criterion for protection was taken as a pipe-to-soil potential of .3 volts, with normal pipe-to-copper sulphate potential being taken as .54 volts. In consideration of the improved performance possible with permanent ground beds, the rectifier characteristics were selected as follows:

Single phase, 110-220 V, a-c, cathodic protection, selenium rectifiers, in weather-proof boxes for pole mounting, with d-c voltmeter and ammeter, control for varying d-c output, 50 amperes, 24 volts, d-c. The rectifiers are equipped with a thermal switch, which transfers to a 50 percent reduced, a-c voltage if the selenium stacks become too hot; i.e. have greater than a 35° C temperature rise.

The anodes, or ground beds, were designed to give minimum resistance or energy cost, consistent with minimum investment and depreciation. Metal in the ground beds was provided to meet current requirements, on the basis of loss of 20 pounds of iron per ampere per year, on a ten year basis. Ground resistivity was sufficiently low and stable at a 6-foot depth, and the anodes were installed in trenches on this basis. Scrap 10-inch steel pipe was welded into 150 foot sections, and placed on a 6-inch layer of tamped coke breeze in the bottom of the trench. Another 6-inch layer of breeze was placed over the pipe, tamped, and the installation moistened. The trench was then filled to within 18 inches of the top with alternate layers of ½-inch rock salt and soil, using a total of 1000 pounds of salt. The top of the trench was filled with soil only. A 4-inch riser pipe was welded to the center of the anode, coated and wrapped, and brought 18 inches above ground for connecting the positive lead to the anode. Three-eighths of an inch perforations were burned in the bottom of the anodes on 8-inch spacings, for later admission of a brine solution through the riser, if it became necessary to lower ground bed resistance.

Typical results obtained from cathodic protection of the transmission lines are shown in Figure 10.





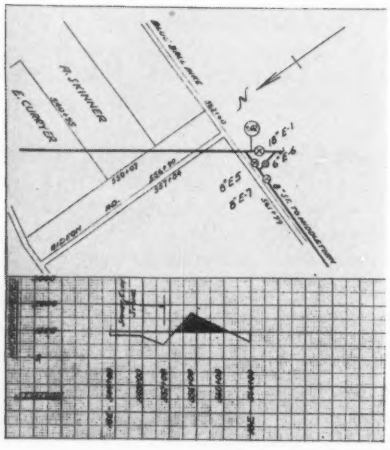


Figure 6—Soil Survey of 18-Inch Gas Transmission Line.

TABLE II—Cumulative Leak Record per 1000 Feet.

MONTH	Protected Section	Unprotected Section	Entire Line
January	.21	.21	.14
February	.21	.28	.18
March	.21	.28	.22
April	.21	.36	.28
May	.28	.43	.59
June	.35	.50	.75
July	.35	.50	.77
August	.35	.50	.87
September	.56	.50	.92
October	.56	1.28	1.29
November	.56	1.99	1.56
December	.64	4.30	1.90

After the units were placed in operation, the pipe was generally negative with respect to the soil, and was thus receiving cathodic protection. Operating data indicate a monthly protection cost of approximately $17.00, based on a one cent per kilowatt hour energy charge. A record of leaks for the year subsequent to protection, as shown in Tables II, indicates the effectiveness of the results obtained.

Distribution Mains

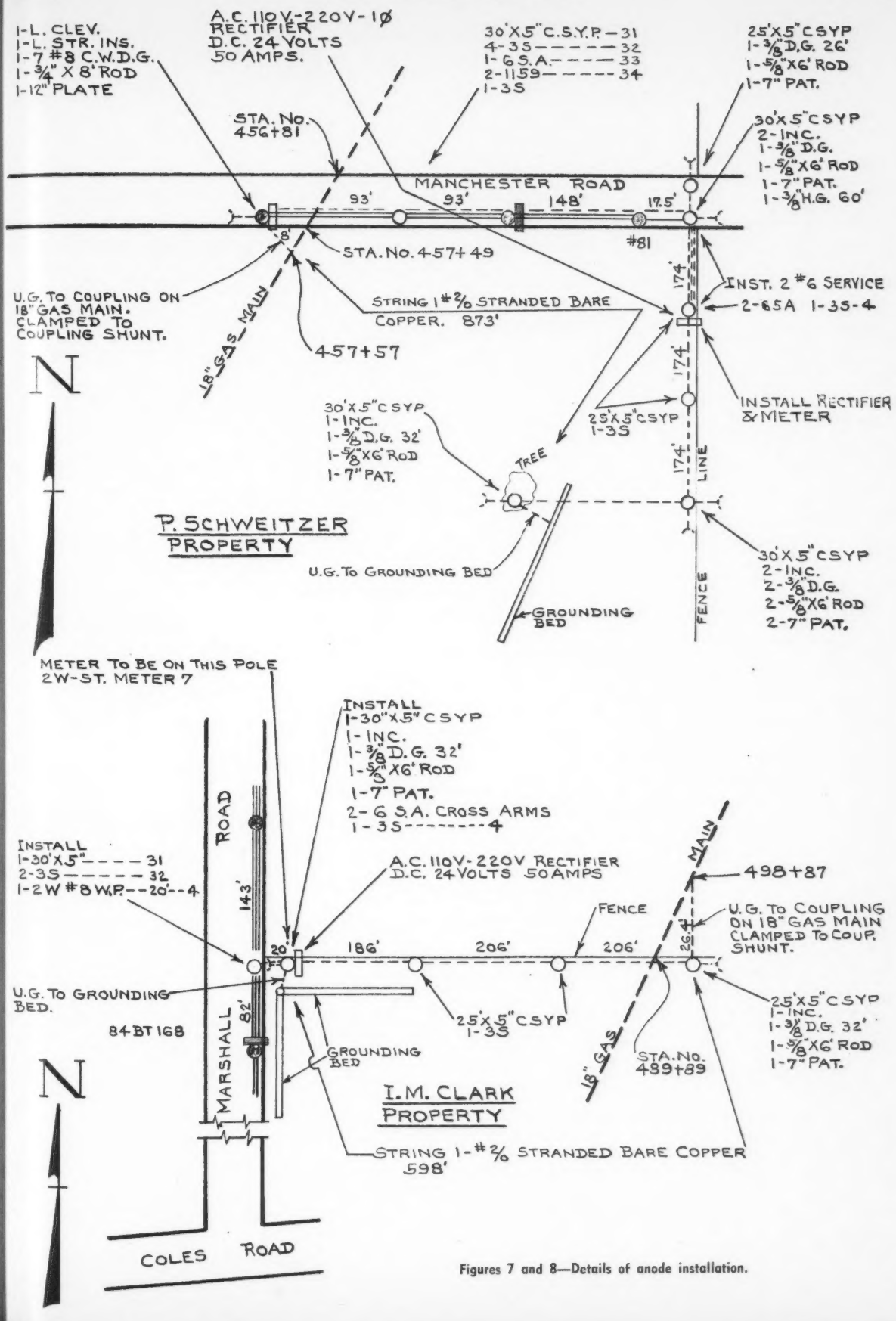
An example of cathodic protection applied to gas distribution mains is the case of a 20-inch intermediate pressure feeder in Tennessee Avenue, from Paddock Road to Reading Road, Cincinnati.

The main is an important connection between the Norwood Measuring Station, and the distribution system to the west and south. It is 20-inch O.D., bare, plain end, steel pipe, with unbonded, mechanical couplings. The line is 40 years old. Leak records showed several repairs in the Tennessee Avenue section.

In 1947 the City of Cincinnati began an improvement of the street, which will put the main under a 40-foot concrete pavement. This situation and the fact that the line could not be taken out of service for major overhauling, indicated the desirability of installing cathodic protection.

To substantiate and investigate the corrosive nature of the ground, a soil survey was made along the gas main. Corrosivity was determined by means of the Columbia Rod. A ground megger was used to measure resistivity for use in designing the protection system, and to verify the corrosivity measurements. The results are shown in Figure 12, and they indicate a corrosive soil all along the main, particularly in the part near Reading Road.

After the need for cathodic protection had been established, it was necessary to decide the type that would be best suited to existing conditions. If a single anode and rectifier were installed, current density at the surface of the main could only be made uniform by separation of the anode and the pipe by several hundred feet. This was impractical along Tennessee Avenue. Such an installation also involved the possibility of damage to adjacent underground structures. The economics of a single anode cathodic protection system for the 20-inch main in



Figures 7 and 8—Details of anode installation.

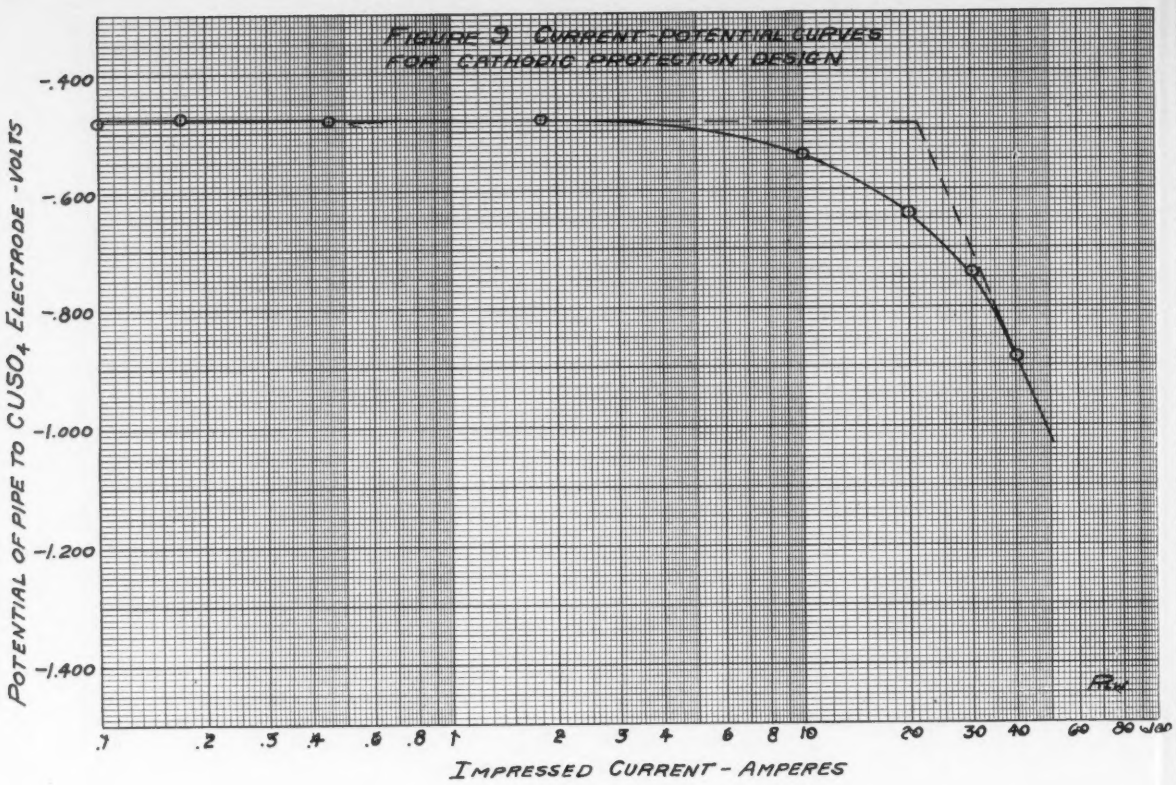
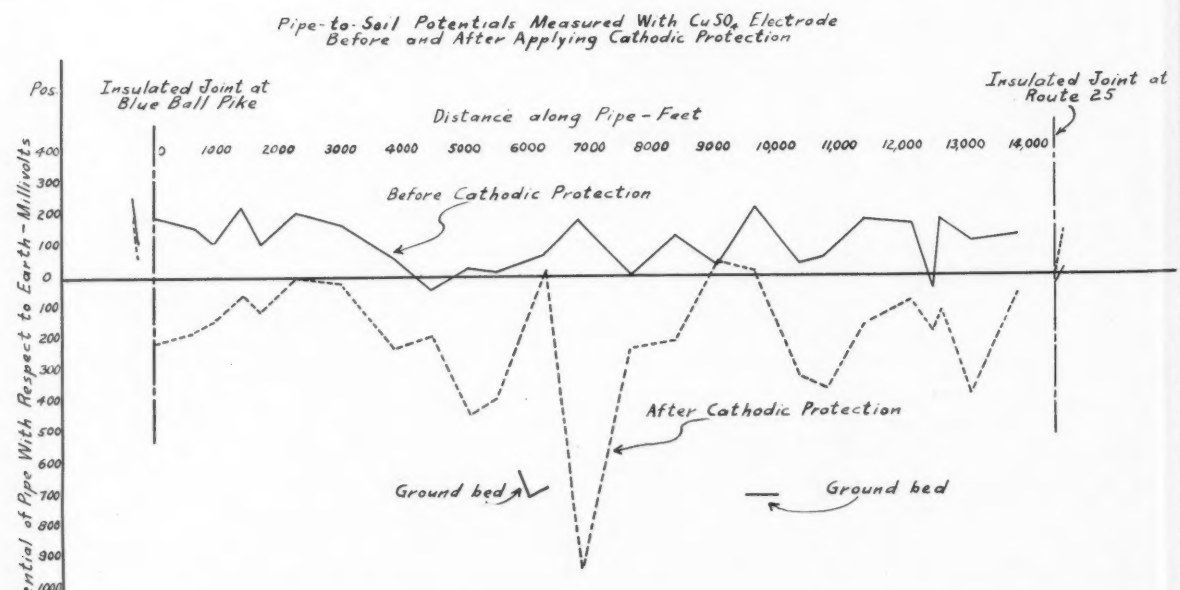
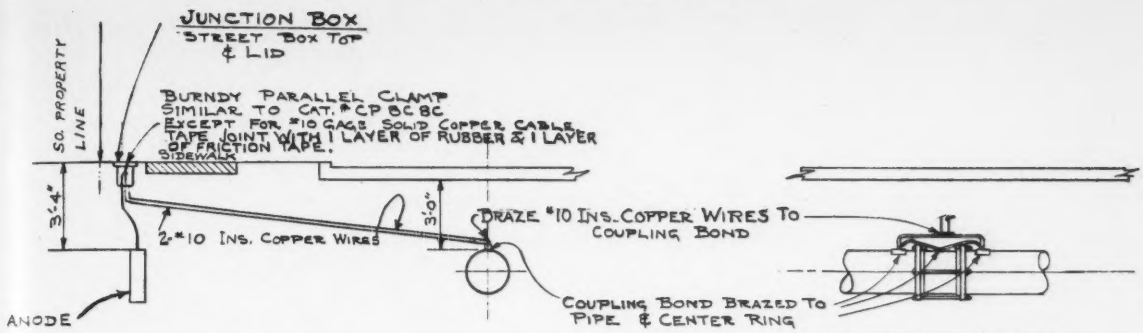


FIGURE 9. CURRENT POTENTIAL CURVES FOR CATHODIC PROTECTION DESIGN
POTENTIAL OF PIPE TO CUSO4 ELECTRODE - VOLTS
-.400
-.600
-.800
-1.000
-1.200
-1.400
.1
.2
.3
.4
.6
.8
1
2
3
4
6
8
10
20
30
40
60
80
100
IMPRESSED CURRENT - AMPERES

Figure 10.


Pipe-to-Soil Potentials Measured With CuSO4 Electrode Before and After Applying Cathodic Protection
Pos.
Potential of Pipe With Respect to Earth - Millivolts
400
300
200
100
0
100
200
300
400
500
600
700
800
900
1000
Neg.
Insulated Joint at Blue Ball Pike
Insulated Joint at Route 25
Distance along Pipe - Feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
Before Cathodic Protection
After Cathodic Protection
Ground bed
Ground bed


JUNCTION BOX
STREET BOX TOP & LID
BURNDY PARALLEL CLAMP SIMILAR TO CAT. # CP 8C 8C EXCEPT FOR #10 GAGE SOLID COPPER CABLE. TAPE JOINT WITH 1 LAYER OF RUBBER & 1 LAYER OF FRICTION TAPE.
SIDEWALK
SO. PROPERTY LINE
3'-4"
2-#10 INS. COPPER WIRES
3'-0"
BRAZE #10 INS. COPPER WIRES TO COUPLING BOND
COUPLING BOND BRAZED TO PIPE & CENTER RING
ANODE
AMERICAN STEEL & WIRE CO.
PIPE COUPLING SHUNT

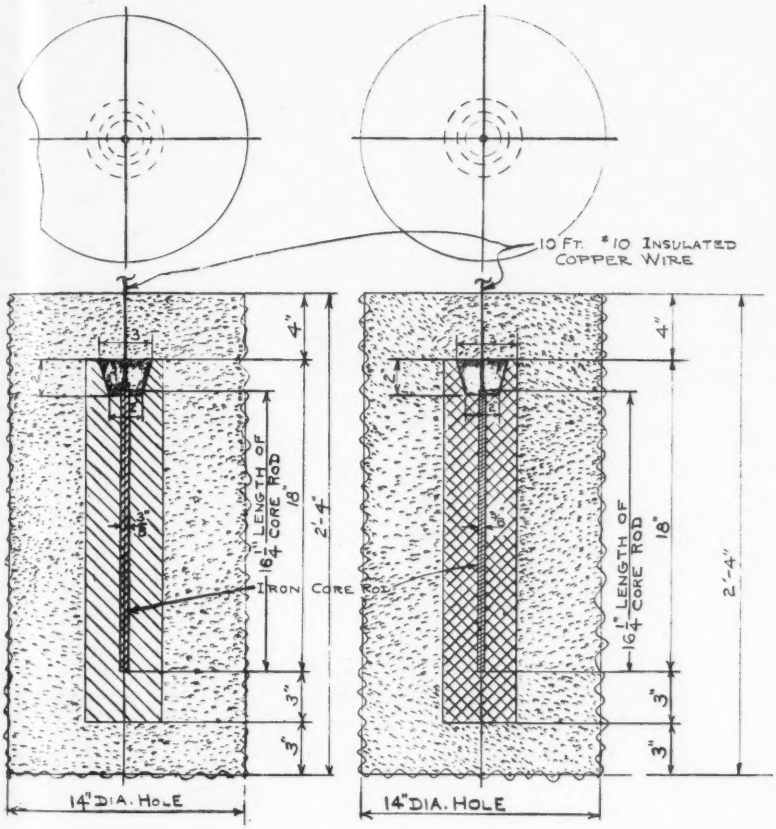


Figure 11—Details of anode installation.

Tennessee Avenue were investigated, as follows:

Investment Required

Land Rights	$ 500
Power Circuit, including line and poles	500
Rectifier Installation, including instrument and connections	800
Ground Bed, including pipe, carbon, salt, and connections	1800
Total	$3600

Annual Operating Expense

Operation and maintenance	$150
Depreciation, 6.67%	120
Energy purchased, 8,000 kwhr.	80
Total	$350

The estimates above are based on a current density at the protected surface of 1.5 ma per square foot; total circuit resistance of 1.25 ohms; total current of 19 amperes, d-c voltage of 24 volts, overall efficiency of 50 percent; and loss of 300 feet of 10 inch steel anode at 20 pounds per ampere per year.

The use of distributed galvanic anodes eliminates the outside source of energy, accomplishes protection at low voltage, and eliminates the danger to other underground structures. The design of such a system was investigated by means of the comparison shown in Table III.

Galvanic anodes were selected on the basis of one anode per pipe joint; using each street opening for the anode wire and the coupling bond. To get practical experience, both magnesium and aluminum anodes with wet and packaged backfills, were installed in soils of different resistance. Anodes were buried at main depth, and were located back of the sidewalk, with a curb-box over the connections for future testing. The anode-to-main spacing was based on 75 percent of the length of the section to be protected. Insulating couplings were recommended at the ends of the protected section. The anodes were specified to have steel core rods, drilled 11/32 inch, one inch deep, for the use of expanding type anode connectors.

TABLE III

	Zinc	Magnesium	Aluminum
Standard anode (Wt. in Lbs.)	18	16	30
Cost of Anode and Backfill, each	$6.50	$8.55	$13.90
Cost of Anode and Backfill, per lb.	$0.36	$0.535	$0.463
Ampere hours per lb.	335	600	675
Life of Anode, years	23	15	30
Open-Circuit anode potential (Volts)	1.1	1.6	1.1
Current output per anode, (ma)	30	75	75
No. of anodes required	217	87	87
Current density (ma/sq. ft.)	.72	.72	.72
Total Cost of anodes and backfill	$1,410.00	$745.00	$1,210.00

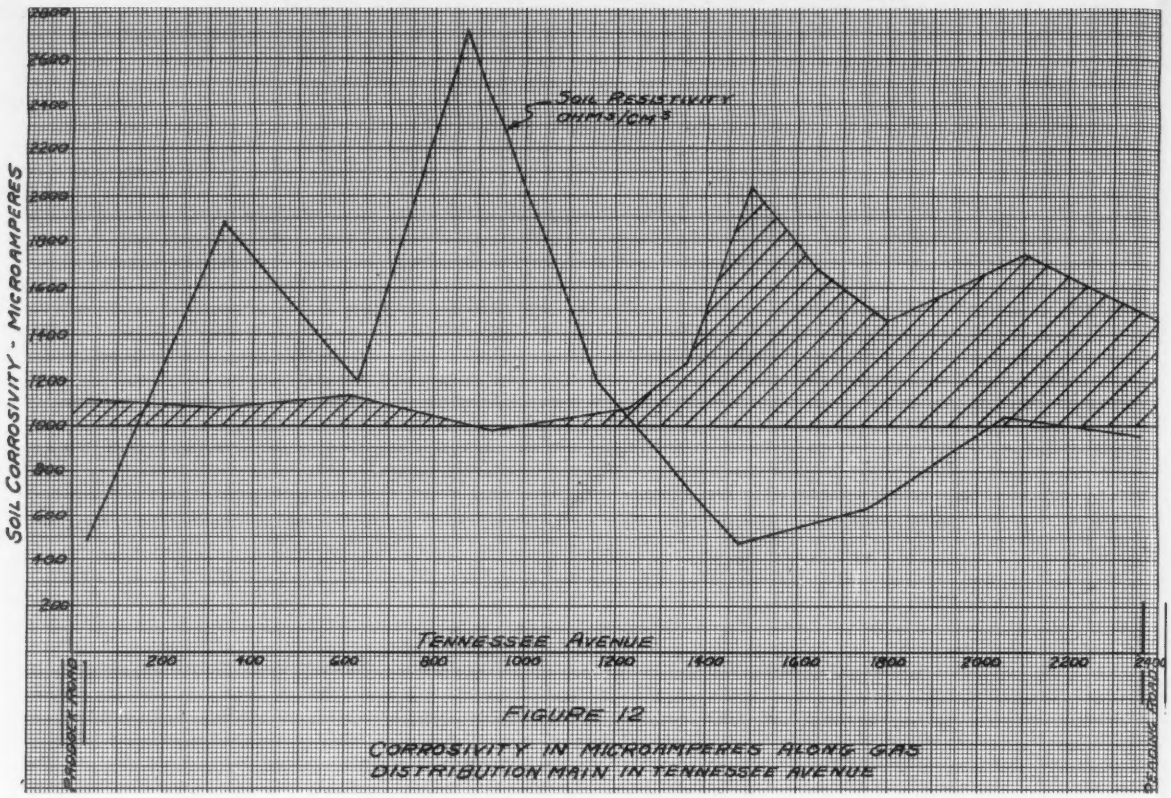


FIGURE 12

CORROSIVITY IN MICROAMPERES ALONG GAS DISTRIBUTION MAIN IN TENNESSEE AVENUE

No. 10 plastic covered wires were used between the anodes and the main. This arrangement is easiest to install and most economical. It has been shown that synthetic resin is the best available moisture resistant wire covering. Couplings and center rings were bonded with copper pipe-coupling shunts, with welding terminals. The anode wires were attached to the main with welding socket terminals. The wire from each anode and the wire from each main connection were brought together in a junction box by means of a bolted parallel clamp to facilitate future testing. The backfill compositions were as follows:

Low Resistance Soils — Bentonite 3 parts, 48 pounds; gypsum, 1 part, 16 pounds.

High Resistance Soils — Bentonite 2 parts, 32 pounds; gypsum, 1 part, 16 pounds; anhydrous sodium sulfate, 1 part, 16 pounds.

Because of delays in the street improvement program over the winter, it has not been possible to finish the galvanic anode installation. Preliminary potential and current measurements have been taken, with results as shown in Table IV below.

Preliminary results indicate desirability of using magnesium anodes because of their higher anode potentials and current outputs, although it is believed that aluminum anodes will be more economical over a long period of time. Output of the anodes is well within the results to be expected, and it is believed that adequate protection will be achieved when the installation is completed.

TABLE IV

Test of Galvanic Anodes—Tennessee Avenue.

Anode No.	Soil Resistivity Ohms/CM³	Type Anode	Potential Cu SO 4- Pipe Open Circ.	Potential Cu SO 4- Anode Open Circ.	Potential Cu SO 4- Pipe Closed	Red in EMF.	Current MA	MA Sq. Ft.
1	2500	Mg	540	1590	640	—100	81	.775
6	1750	Al	480	960	650	—170	69	.565
7	1680	Mg	640	1600	660	— 20	84	.805
9	1600	Al	550	960	550	0	64.5	.615
12	1500	Al	540	1100	540	0	111	1.06
24	1250	Mg	550	1580	600	50	97.5	.93
28	1450	Al	600	1100	620	— 20	90	.86
29	1600	Mg	640	1560	660	— 20	33	.317
32	4250	Al	550	1150	570	— 20	30	.286
33	4450	Mg	580	1650	600	— 20	54	.515
34	4500	Mg	580	1600	600	— 20	43.5	.417
35	4600	Mg	560	1540	580	— 20	54	.515
36	4700	Al	620	990	620	0	33	.316
37	4500	Mg	580	1610	600	— 20	39	.374
38	4400	Al	540	1080	550	— 10	36	.344
40	4050	Mg	590	1650	580	+ 10	43.5	.417
40	3400	Al	480	1140	500	— 20	42	.4

Experience at Bagnell Dam To Prevent Corrosion of Underwater Steel and Iron*

By TURNER WHITE, JR.

IN DELINEATING efforts of the Union Electric Company of Missouri at Bagnell Dam to find a satisfactory means of protecting the steel and iron continuously submerged, only methods used in the application of theories and experiences developed by others will be presented.

While the theory of electrochemical corrosion is believed to have been advanced first about the beginning of the century,[1] it was not until almost 25 years later that any pointed effort was made to apply it to protection of iron and steel. This was done by some oil and pipeline companies. It was some ten years later before the theory was used in an attempt to protect the inside of elevated water tanks.[2] This account of the time intervening between the discovery of the cause and the practical application of control measures is given to point out how slow changes are made and the application of new knowledge is achieved.

TURNER WHITE, JR.
Superintendent of Construction, Engineering and Construction Department, Union Electric Company of Missouri, formerly System Superintendent Hydroelectric Plants Department, Union Electric Company of Missouri.

During the last ten years extensive use has been made of this theory for the protection of both pipelines and water tanks with considerable success and economy. However, it apparently has been very sparingly applied elsewhere. Many industries with large volumes of exposed steel and with electrical engineering talent available have shown only a very mild interest.

Since it is the burden of the civil engineer to provide the best iron and steel members for any job, perhaps it is in order for him to encourage the electrical engineer to furnish a design for protection against corrosion, particularly in those cases where members are exposed, or subject to electrochemical action. When it is realized that any iron or steel in water will develop galvanic action with currents circulating, and that one ampere flowing from the metal will remove twenty pounds in one year's time,[2] it would seem to warrant an extended effort to prevent resulting losses.

At Bagnell application of measures to protect steel and iron began soon after the plant was constructed. In addition to the usual exposures of penstocks, head gates, trash racks, stop logs and other items that could be reached by unwatering means, there were steel guides and anchor bolts which could be reached only by very costly methods for replacement after failure. It was felt that even though the original installation, left unprotected would last 30 to 40 years, the life span might be doubled by application of reasonable protection.

About 1938 first experiments were begun to learn if cathodic protection could be applied successfully. In one area provided for future units an ideal location existed. Here control tests could be made without interference from debris and water velocities.

With the use of an ordinary automobile battery charging set and several pieces of steel, with surfaces at various stages of corrosion from bright to heavy rust, experiments were undertaken. Test samples were spaced at varying distances from the positive electrode to give an indication of electrode spacing that would produce best results.

After approximately one year's observation of the test pieces, it was determined that a calcium deposit could be produced on the steel with no evidence of rust on surfaces facing the electrode. It had been believed that heavily corroded samples subjected to the test in time would drop their rust scales. Observation showed this did occur, but only to a small extent. It did indicate, however, that further corrosion of

★Presented at the Annual NACE Conference, St. Louis, Mo., April 5-8, 1948.

badly rusted surfaces could be arrested without prior removal of the scale.

With these seemingly successful test results as a basis, plus experience of others and using the same battery charger, an installation was made in a service water tank. It is a 50,000-gallon tank of the usual cylindrical sides and hemispherical bottom elevated above an 80-foot 36 inch in diameter standpipe.

The first electrode used was a 1-inch stainless steel rod which proved satisfactory for about three years. The next electrode was an aluminum wire, which remained in use a few months only. Then, upon recommendation of a manufacturer, a platinum wire of very small diameter was installed.

During this period of several years' application, electrical current was not kept constant because of failure of the electrodes and because ice in the tank broke the connection, often with the loss of the electrode.

Some details of the installation within the 50,000 gallon storage tank follow:

The length of the electrode was 18 feet and the lower extremity reached 2 feet into the bowl. The height of the bowl or hemispherical bottom is 8 feet and the height of the cylindrical part of the tank is 17 feet. Twenty-two volts was applied to the single electrode in the center and measured 2.2 amperes of current.

Water in the tank averages about 4 grains of hardness and a pH of 7 plus. Surface fluctuations extend through a range of approximately 7 feet. This fluctuation often occurs under ice conditions, making it difficult to maintain the electrode.

Chemical analysis of the water is as follows: SiO_2 — 8.0; Fe — 0.2; Al — 0.1; Na — 32.3; Ca — 35.7; Mg — 9.8; SO_4 — 38.3; Cl — 10.8; $CaCO_3$ — 129.0; N — 0.85.

However, it was evident early that protection was being provided in the cylindrical part of the tank. Hoped for protection was not being secured in the hemisphere bottom, nor was it being obtained in the standpipe. Calcium deposits forming first at points nearest the electrode, had been expected to provide insulation against the currents and divert them progressively to more distant points, eventually to the bottom of the standpipe. This still is believed to be theoretically possible but too long a process for practical application.

Now a separate electrode reaching into the standpipe only is being placed and is expected to do the job.

During this period of experimentation on the water tank, protection of crest gates also was undertaken. There are 12 of these taintor gates with surface areas of about 30 by 20 feet, submerged except in low water periods.

For this installation a rectifier of 12 volts and 6 amperes capacity was secured. Two wrought iron pipes were installed as electrodes on each gate (only two gates have been equipped to date). These applications have not been continuous because of the loss of electrodes and the periods without application have been unnecessarily long. Principal cause of the loss of electrodes has been failure to remove them when gates were opened during floods. Replacement following their loss often was delayed. In spite of this, however, some protection has been observed and the installation could be made adequate. Some rust has appeared because there are periods when surfaces are exposed to the air as a result of lake draw-down.

An attempt has been made to protect the trash rack guides and stop log guides as well as the trash rake guides. None of these surfaces can be reached by unwatering and are continuously submerged.

Efforts at these points have not been successful because the electrical currents manage to stray elsewhere than points intended. It is believed, however, that if sufficient capacity were installed, results would be readily apparent and at an easily justifiable cost.

Some thought has been given to protection of the penstock where water velocities are rather high, but so far it has been impossible to design an installation which would not be carried away in a short time.

As a substitute for cathodic protection in the penstocks and on head gates, many paints and degrees of surface preparation were tried. All these experiments point to the use of two coats of aluminum applied on a bright metal surface as giving best results.

In penstocks and on head gates, more than 70 percent protection is retained after about six years. Primers or red lead used as a first coat under the aluminum were fairly satisfactory, but not to the extent of two coats of aluminum.

It has been observed repeatedly that in any power plant and in almost all other plants, there are extensive surfaces of iron, steel, lead cable and galvanized duct exposed to soil or water, which will corrode if left unprotected—sometimes in an embarrassingly short time. Instances are of record of lead cable failure within a few months after installation. Such items as sheet piling, intakes, pipelines, condensers and the bearing piles which support many large structures and to which a grounding system is attached, are all subjects for consideration. If means to prevent electrochemical action were considered during the design period, great waste, cost and inconvenience could be avoided.

A short paragraph by M. C. Miller of Ebasco Services, Inc., believed to be a helpful thought, is quoted below:[3]

"Electrical engineers should be made corrosion conscious so that they can design against corrosion, not for corrosion. It would seem that any fairly large electrical utility could well afford to have a high class corrosion engineer who would be consulted in all design practices to guard against designs which cause corrosion."

References:

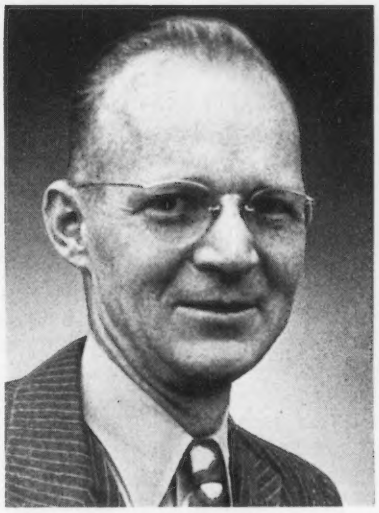
1. Corrosion—Causes and Prevention, by Frank N. Speller.
2. Cathodic Protection for Water Works, by W. D. Loreaux, Paper before Second Annual Meeting, Michigan Section, Am. Water Works Assoc., Sept. 20-22, 1939.
3. Electrical Industry Engineers Responsibility for Design against Corrosion, by M. C. Miller.

Corrosion Problems in Water Wells*

By DR. T. E. LARSON

CORROSION OF water works equipment and installations is a major item since it may result in 1) interrupted service, 2) inferior water quality and 3) excessive cost of maintenance. Many public and industrial water supplies come from wells. In Illinois alone there are about 200,000 water wells, of which some 3000 produce water for municipal and industrial purposes. These wells have depths varying from 15 to 2200 feet, with pump settings of 10 to 700 feet and capacities up to 2000 gpm.

Economics sometimes dictates that corrosion be ignored because the cost of replacement may be less than the cost of prevention. However, in many cases, the cost of pulling and resetting a turbine pump exceeds the cost of the pump. The economic loss due to interrupted service is also an important consideration.



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Corrosion is concerned with metals, combinations of metals and their environment. When the known facts concerning the rate of corrosion of the various metals are considered in association with many factors involved with such environmental conditions as are encountered in many water supplies, a multiplicity of causes is apparent for corrosion in wells.

Perhaps the first step in clarifying the problems is to consider the metals and combinations of metals used in construction of the vertical turbine pump. These metals ordinarily are bronze, cast iron, steel and stainless steel. Although often used together with no serious harm, combinations of copper-bearing metals with cast iron or steel always offer a possibility for serious damage depending on the relative surface area and location, and on the environment.

Galvanic Attack

In Figure 1, it is evident that concentrated attack can (and does) take place on a steel impeller shaft due to the small area of shaft exposed between the bronze bearing and a large area of bronze impeller. The presence of salty or high mineral content water decreases resistance in the path of the current and thereby increases the flow of current and the subsequent loss of metal.

The importance of the shaft as a conveyor of mechanical energy is second only to the impellers which by design impart this energy to the water. Because impellers are vital components they have long been made of bronze to provide long life. Of recent years, the impeller shaft and often the total shaft length has been specified as stainless steel.

On close inspection, another accidental factor is evident in the arrangement of these bimetallic couples. The location and contacts often permit a doubled galvanic potential and thereby a doubled rate of corrosion. This is similar to short circuiting the open terminals of two batteries which have been connected in series, and it has often been noted in water-lubricated pumps as in oil-lubricated pumps where water is permitted to enter the lower end of the oil enclosure tube.

In Figure 1, it is obvious that self-imposed current can flow from the cast iron bowls to the impellers and be conducted up the shaft to flow to the bearings or bearing retainers and return to the bowls by way of conduction through the column pipe or the oil enclosure tube.

Naturally the concentrated current flow from the bowls to the impellers takes place at the impeller skirt where close clearance provides a path of least resistance. Here is the "heart" of the pump where slippage cannot be allowed without impairing efficiency. In many cases manufacturers circumvent this by inserting a permanent or replaceable bronze wear ring around the impeller skirt, thereby eliminating accelerated corrosion at this vital point by transferring it to less vital areas and reducing the concentrated attack. All-bronze bowls are becoming common, their cost adding some 80 percent to the cost of the turbine unit but often adding only 10 to 20 percent to the total installation cost.

Carbon Dioxide

Another serious point of corrosion in turbine installations exists inside the column pipe and outside the oil tube. It is observed as pitting, particularly (some 6-24 inches) just above the discharge bowl of the turbine unit and to a progressively lesser extent up the column pipe above the spiders or the bearing supports. It will be noted that each of these points is located where there has been a sudden change

* A paper presented at the annual meeting of NACE in St. Louis, Mo., April 5-8, 1948.

from velocity head to pressure head, the maximum pressure head being just above the turbine unit. Similar pitting often is noted in the turbine unit on the high pressure side of the guide vanes.

A theoretical explanation of this corrosion involves the assumption that gas bubbles are released from the water at low pressure points on the under side of the impellers, at constrictions and in eddies created by the rapid changes in velocity, in direction and in pressure within the turbine unit. Although designers justly refer to streamline flow, it is obvious that such streamlining can be no more than just relative, since the flow through such units is always turbulent flow.

As the water is passed through each successive impeller the water and the gas are subjected to increased pressure and on leaving the discharge bowl an enlarged diameter converts some of the velocity head to additional pressure head. This increased pressure provides a greater solution potential for the released gases. These gases are nitrogen, water vapor and carbon dioxide and as they dissolve the water film or surface of each bubble becomes excessively acidic by the formation and slow diffusion of carbonic acid. As these gas bubbles with acidic surface films pass over the metal, corrosive action is enhanced. As the water moves up the column pipe the number of bubbles decreases; the pressure of gas within the bubbles decreases, and the relative amount of corrosion decreases accordingly. The presence of dissolved oxygen or hydrogen sulfide can accelerate this type of corrosion and a "worm-eaten" shaft or shaft tube is not unusual for extreme cases.

This type of CO_2 attack at high pressure points also has been noted in booster pumps and in valves and elbows on the high pressure side of booster pumps.

In one case a 1000 gpm vertical turbine installation at a 500-foot setting required a replacement of the lower 100 feet of column pipe after 33 months' service during which time 1274 million gallons had been pumped. This same unit was then set at 600 feet and after 547 million gallons had been pumped during 17 months it became necessary to pull the pump again. The lower 100 feet of column pipe was in worse condition after 17 months than the previous lower 100 feet appeared after 33 months. In this case the lower pump setting (due to water level recession) necessitated a greater pressure at the discharge end of the turbine unit. Table I shows the difference in pressure between the upper and lower end of the turbine unit.

TABLE I

DATE	Pumping Level Feet From Ground Surface	Rate gpm	Difference in Pressure (Ft.)
1942	422	830	464
1943	456	830	498
1944	488	830	530
1945	491	660	...
Pump inspected and replaced at 600-foot setting.			
1945	521	820	...
1946	541	830	583
1947	561	830	603

Pump removed, holes in column pipe and graphitization in bowls caused loss n capacity. Weight loss in a random section of column pipe was 25 percent n 4½ years.

The carbon dioxide content of this water was about 40 ppm, the total mineral content 720 ppm and hydrogen sulfide was just noticeable, possibly 0.5 ppm.

Waters of high free CO_2 content produce the same result even in shallow settings.

For the deep settings, the purchase cost of column pipe, shaft and shaft tube often is greater than the cost of the turbine unit itself. Protection of the pipe by hot application of coal tar paints can be obtained for the additional cost of 50 to 100 percent of the cost of the pipe itself. Other coatings can be used, the cost being greater or less, but in general better coatings are the more expensive. No coating however costly will be effective without proper treatment of the metal and proper application.

Since the greatest degree of attack occurs within 10 or 20 feet above the bowls, some installations specify bronze column pipe and shaft tubing and stainless steel shaft for this distance above an all-bronze turbine unit. Hand painting the brass and the steel for a distance of two feet on either side of the junction reduces the possibility of galvanic attack.

The use of a suction pipe of excessive length and even any suction pipe or strainer is being discouraged in many installations. The advantages very often are nullified by the recommended use of an airline, thereby insuring a pumping level above the bowls and also a lesser pressure drop from the well bore to the entrance to the turbine unit.

Another type of corrosion occasionally encountered is at the water line on the outside of the column pipe and is particularly abusive when concentrated at threaded couplings which have not been painted.

Stray Currents

With regard to stray currents, no one should blame stray currents for electrolysis or corrosion on assumption alone without first testing for their absence or presence. Stray current electrolysis can be a cause for corrosion and the results of such corrosion presents a pitiful picture, but its prevalence appears to be much less than commonly assumed. Too often the pump manufacturer or sales engineer refers to "electrolysis" as the cause of corrosion, thereby implying that the source of electric current is from an external source. In many cases stray currents or current from an external source is not observed and the actual source of current is within the pump itself.

The author has investigated some 80 pumps in Illinois with J. B. Millis, field engineer, for the Illinois State Water Survey and in only a few places could corrosion be attributed definitely to stray currents. Electrified railways were in the near vicinity of most of these. Out of some 50 tests about 40 percent showed a varying potential difference between discharge line and pump head or between the pump head and the well casing. However, the magnitude of the potential difference did not exceed 0.4 volt and the current flow did not exceed 1 ma. In several cases 0.8 to 2.5 volts were recorded. Of all the cases investigated, roughly 60 percent showed a constant po-

tential of 0.1 to 0.4 volts, well within the range of normal galvanic magnitude.

One effective method of reducing effects of stray currents consists of insulating the pump assembly from the well casing and the discharge line. Conduit for power cables also should be insulated from the pump head.

Another method used for controlling the path of current flow consists of bonding the column pipe, either by welding a brass rod across the flanges, or attaching a copper strip along the outside of the full length of the column pipe from the bowls to the surface and grounding it at the top of the well. This bonding is devised to carry most of the current outside and away from the inner workings. No inspection has been made on the effectiveness of this procedure. The relative current carrying capacities of ordinary metals and alloys requires some consideration when attempting this procedure. The possibility of galvanic attack also should be eliminated by coating the bonding metal.

TABLE II

METAL	Specific Resistance Ohm per cm Cubed	Relative Cross Section Area for Equal Carrying Capacity
Copper	1.7	1
Brass	7.0	4.1
Pure Iron	10	5.9
Soft Steel	16	9.4
Monel	44	26
Cast Iron	75–98	44–58

Cathodic protection has been used in several cases to combat this and other types of corrosion. No before and after inspection has been made to determine the effectiveness of these installations.

The use of a one or two-foot band of zinc around the outside of the tail pipe has been attempted to prevent some types of corrosion. Obviously results could not hope to be nor were they effective.

Well Casing

With regard to well casing little specific data are available on actual life, although 10 to 20 years appears to be the limit in the general opinion of Illinois water well drillers. Wrought iron is believed to be superior to steel. Actual life will depend on the purpose for which casing or liners are used, quality of the water, the shale, sandstone, limestone or soil in contact and on possible presence of stray or galvanic currents.

If casing is used to exclude poor quality water it always is advisable to pressure grout a two-inch annular space around the outside of the casing to perfect the seal and to protect the metal against corrosive action.

One unrecognized source of corrosion of casing consists of setting an all-bronze pump inside a steel casing and permitting metallic contact between the pump head and the top of the casing. This automatically sets up a battery in which the casing becomes the anode. This is fatal, particularly if the pump diameter is very near the inside diameter of the casing or if the pump is not centered within the

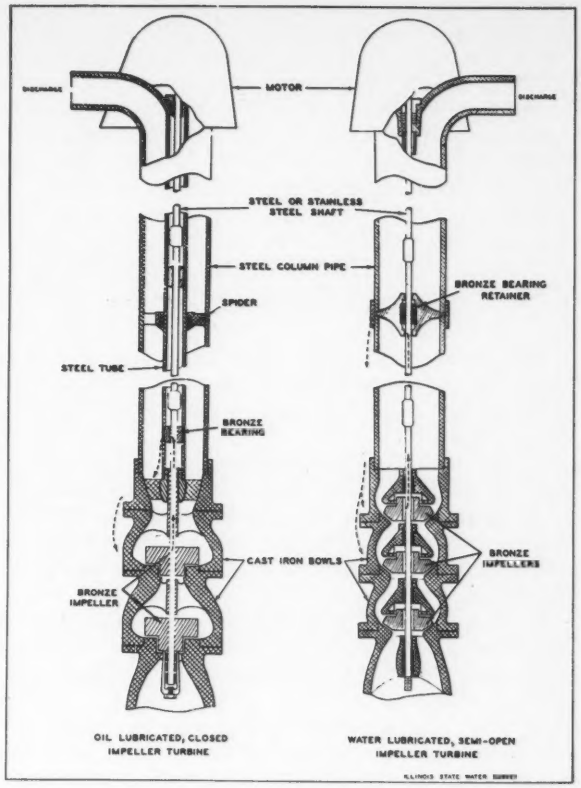

Figure 1—Cross-section showing areas within deep well pumps subject to corrosion attacks.

casing—a very difficult thing to do. Effects are noticeable particularly when pump capacity is low, such as that of bronze-bodied jet pumps and the periods of operation are short. The author has noted 2-10 ppm iron in the discharge under normal operating conditions at a private home well which obtains its water from an iron-free source.

Insulation at the pump head-well casing and using a non-conducting well seal is one solution to this problem, but it is recommended that the bronze body of the pump unit be coated to decrease the area of bronze exposed to the water. This also helps to nullify the effect of possible contact with the casing at some point in the well.

The fact that corrosion takes place in water well equipment is forcibly brought home when samples of water are collected over timed intervals on starting a pump. Excessive iron during the first few minutes is noted in nearly every case. In some instances this may be attributed in part to the presence of water from a secondary source in the well or from behind the casing. In others a portion of this iron may represent that from the water itself which sloughed off the pump or well screen on the start of water movement.

Paint the Cathode!

With the present tendency in pump design to replace ferrous metals in part or as a whole with brass or bronze, it should be pertinent to advise that this excellent non-corroding bronze be coated or painted

wherever possible to prevent increasing serious attack on steel and cast iron in the vicinity of the increased area of copper-bearing metal. This corrosion preventive is applicable to all water works fixtures where too often the steel or iron is coated to prevent corrosion but is thereby more seriously corroded at pinholes and flaws in the coating where accelerated galvanic attack takes place.

DISCUSSION

*By Raymond H. McLeod**

Dr. Larson has presented a very complete paper covering the causes and experience of corrosion of deep well pumps. The following points are particularly important.

1. The effect of water resistivity on the rate of corrosion will vary due to the dissolved mineral content, because as total dissolved solids increase resistivity of the water decreases, and therefore the resistance of the path for galvanic or stray currents is decreased.

2. That stray currents were blamed too often for a corrosion problem in pumps before measurements were made to determine the magnitude of such currents present.

3. The coating of the cathode area to reduce galvanic effects. This may warrant further mention because of the relative areas of the anode to the cathode usually found in pumps. In the case of deep well pumps, too much emphasis can be placed on the coating of the column pipe and shaft housing which normally constitute the anode area and not enough on the coating of the cathode or more noble metal parts. Coating the anode leaves it corroding badly in holidays or breaks in the coating, causing a galvanic cell consisting of a large cathode area and small anode area. Coating of the anodic or steel parts is valuable in reducing current density requirements if cathodic protection is to be applied.[1]

Early in 1941, the Electro Rust-Proofing Corporation made what is believed to be the first application of cathodic protection to a deep well turbine pump. This was installed in an 8-inch pump with 90-foot setting at Lapeer, Michigan. This application, reported previously,[2] to a pump with an average life of 18 months, operated for 35 months and inspection showed no further corrosion of the pump parts. Another application of cathodic protection was made in a deep well pump in industrial use located in Indianapolis, Indiana. This was a 5-inch oil-lubricated Cook deep-well pump, with 137-foot setting. Corrosion history indicated average life of the oil tube and column pipe was seven to nine months. In 1945, inspection of the pump showed penetration of the oil tubing and column pipe with the pitting on inside of the column pipe and outside of oil tube. On February 16, 1945, protection was installed and one ⅝-inch mild steel electrode was installed in the annular space running the entire length of the column pipe to the pump bowl. Current was supplied to the anode from a rectifier with the negative terminal connected to the column pipe, casing, oil tubing and the motor base. Unfortunately, when the installation was made the pump sections were replaced with old pipe, due to steel shortages at the time. Seventeen months after cathodic protection had been applied, water was discovered in the oil which indicated a failure in the shaft tubing. The pump was pulled July 12, 1946, and inspection indicated that the tube had not been continuously under cathodic protection due to intermittent contact between anode and pump. It was evident that insulation of the anodes at 20-foot intervals was insufficient and new anodes were installed with insulators five feet apart to prevent accidental contact with the column pipe or oil tubing. Reinstallation was completed in November 1946. Two ⅝-inch x 130-foot mild steel anodes were installed between the column pipe and shaft tubing, and two ⅝-inch x 70-foot mild steel anodes between column pipe and well casing. Two circuits were provided from the rectifier to supply specified current density to each set of anodes which were designed for 4-year life. After the first installation, life of the pump had been approximately doubled with greatly reduced metal replacement. Twenty-one months after the second installation, the pump is operating at rated efficiency with current flow at designed values.

A similar cathodic protection system was made in 1945 for an industrial company on the Louisiana Gulf Coast. This pump was a 16-inch Fairbanks Morse oil-lubricated turbine type deep well pump with 106-foot setting.

Cemented well casing, 20″ x 121′4″.
Column pipe, 12″ x 100′.
Shaft tube, 3″ x 106′.
Pump, 16″ x 6′.
Suction pipe, 10″ x 12′ (below pump in well pipe).
Well pipe, 12″ x 57′4″ (below pump).
Screen pipe, 12″ x 80′5″.
Bottom of well, 251′ 7″ below ground level.

The water analysis was as follows: pH, 6.6; Bicarbonate (HCO_3), 103 ppm; Sulfate (SO_4), 3 ppm; Chloride (Cl), 218 ppm; Flouride (F), 0.1 ppm; Hardness as $CaCO_3$, 264 ppm; Iron (Fe), 5.9 ppm.

The corrosion history of this pump showed rapid deterioration in the pump column pipe and shaft tubing, particularly noticeable at pump column junction.

To protect this pump:

Two—100′ x ⅝″ MC steel anodes were installed in annular space between shaft and column pipe.
Two—100′ x ⅝″ MC steel anodes were installed in annular space between column pipe and casing.
One—130′ x ¾″ MC steel anode was installed inside suction pipe and extending below pump into well pipe and screen pipe.

A rectifier was furnished with three special circuits, containing variable resistors, supplying specified current density to:

Circuit No. 1 in the annular space between shaft and column pipe.
Circuit No. 2 in the annular space between column pipe and casing.

* Electro Rust-Proofing Corp., New Jersey.

Circuit No. 3 in the the well pipe, screen pipe and suction pipe.

The anodes were supported by insulated brackets welded every 20 feet to column pipe on the inside to hold anodes for protection of the shaft tube and interior of the column pipe (Circuit No. 1) and on the outside of the column pipe to protect the exterior of the column pipe and interior of casing (Circuit No. 2).

The lower anode was centered in the well pipe and screen pipe by spiders located 40 feet, 80 feet and 120 feet from bottom of well. The spiders were constructed of wood, but during the first anode replacement it was discovered that the wooden spiders had been damaged, so new spiders composed of metal were used in the subsequent anode installation. Electrical connections were made by means of spark plugs seated in the pipe walls. A lead wire from the lower anode was taken from a connection through the suction pipe section and up to the ground level through the annular space between the column pipe and well casing.

This installation was made on July 3, 1945 and the system operated continually until early in 1947, some 20 months after the installation, at which time the pump capacity had dropped from 2900 to 2000 gpm. At this time a calcareous deposit was observed in the discharge pipe of the well. Also no current was flowing to the anode in the well pipe which indicated that it was out of service. The other circuits still operated at required amperage.

The pump was pulled on April 28, 1947, 21 months after the first installation, a new set of anodes was installed and a thorough inspection was made. It was found that the drop in pump capacity was due to the collapse of the wooden spiders, pieces of which lodged in the entrance to the pump section. All surfaces of submerged metal removed by riggers were completely free of any active corrosion. The surfaces inspected were the pump shaft oil tube, column pipe inside and out, and pump bowls and suction pipe. No inspection of well casing could be made since it is permanently installed.

It seems reasonable to expect that magnesium anodes may provide cathodic protection of deep well pumps where electrolyte resistance is not excessive.[3] Experimental applications now in progress may soon offer further data.

Conclusions

1. Experience gained from installations during the past seven years indicates corrosion of deep well pumps may be mitigated by proper application of cathodic protection.

2. Current applied should not exceed the critical current density plus a minimum safety factor to provide maximum anode life.

3. Mechanical supports for anodes should provide rigidity to prevent outages due to anode to pump contact. Submerged connections should be made carefully to prevent loss of anode leads.

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Attenuation Equations Applied to Cathodic Protection By Distributed Drainage★

By E. P. DOREMUS, G. L. DOREMUS and M. E. PARKER, JR.

ATTENUATION equations have been given[1] which describe the variations in current, potential, cathodic current density along a long uniform structure being protected by drainage from a single point. A later paper[2] has described equations derived from these which described the conditions along a structure having a finite number of smaller drainage points. Further modification of the assumptions, including the consideration of an infinite number of small drainage points, leads to further simplification of the resulting equations. This is of particular interest because it is the type of installation employed in the use of magnesium anodes.

The equations derived correlate well with actual experience, which has shown that the total current requirements are usually much smaller with distributed drainage than with the concentration associated with the use of rectifiers. Most of the excessive current used by the rectifier type of protective system is attributable to the wasted power expended in lowering the structure potential in the immediate vicinity of the drainage point more than is necessary for protection; an appreciable part of the loss is the I^2R loss in the structure itself, incident to larger currents flowing through longer sections of the line.

The same nomenclature employed by Pope[1] and later by one of the present authors[3] will be employed. All of these equations are based upon certain assumptions of uniformity, of which the following may be enumerated:

1) The pipe is of uniform section and conductivity. In the usual case of a welded pipeline of uniform unit weight, this assumption is valid. It is usually tenable of a screwed line, but not of a line on which Dresser

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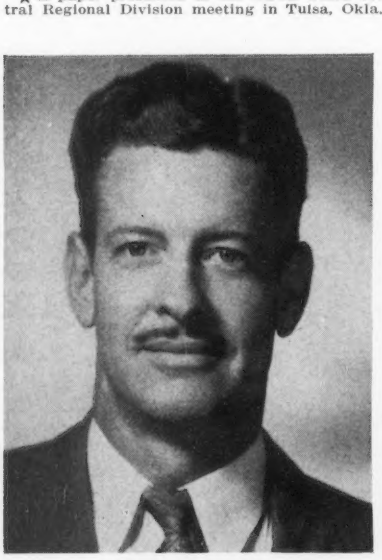

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or similar couplings are used. A composite line must be treated by sections.

2) The soil is of uniform resistivity. This is never true in practice, but even wide variations in soil resistivity produce surprisingly small fluctuations in the curves. Since α, the attenuation constant, varies only as the one-half power of R_L, the leakage resistance; and R_L, in turn, is only partly determined by the soil resistivity, it is perhaps not surprising after all that it should produce so little effect.

3) The leakage resistance, R_L, is constant. Generally this value is no more variable than the soil, being partly determined by soil resistivity. On well-coated lines, it is usually quite uniform. Short sections of repaired and reconditioned lines (with higher than average R_L) and short-circuited bare metal casing (with lower than average R_L) introduce local variations in the plotted curves, but on either side of these disturbances the attenuation is normal.

4) It is assumed that the line is of infinite length. Although this is not actually true, the only effect on the use of the equations is a distortion near the ends of the line; the values away from the ends are essentially the same as if the line were in fact infinitely long; provided that it does not, at the end, tie in to a structure with a ground resistance very low compared to that of the structures under consideration. For example, a well-coated pipeline connected to a terminal where there are large bare tank bottoms will be affected for many miles; a bare line will not be sensibly different five miles away from such a station than if it were actually infinite in length. A pipeline, coated or bare, which is isolated from pumping stations and tank farms by insulated flanges, will show distortions only within a few hundred feet of the insulated joints.

5) Not in the nature of a basic assumption, but a factor subject to frequent misinterpretation, is the change in the effective value of the leakage resistance with the continued application of protective current; an effect described as polarization. It is assumed in all the subsequent discussion that adequate time elapses after the application of test or protection current to permit the polarization to reach a stable value, and it is this value which is used in the equations. Current densities which are too small to effect polarization will not yield results which are applicable to much greater current values; consequently, in determining attenuation constants by test generators, it is essential that the values be derived from measurements taken after sufficient time has elapsed, and only within the effective range of the drainage point.

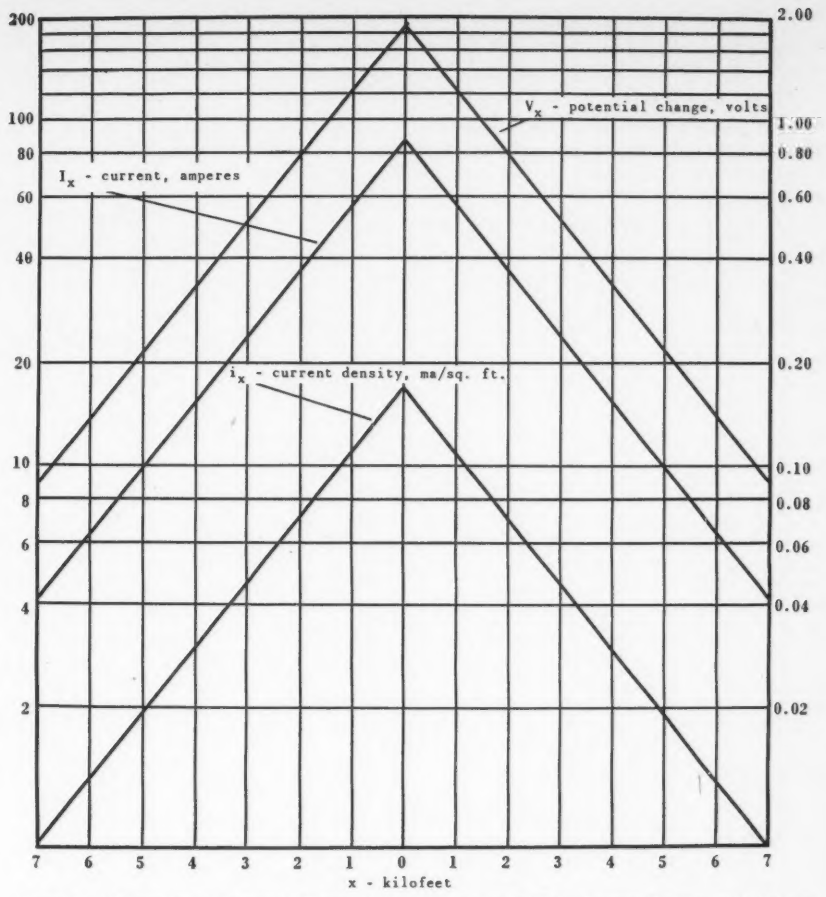


Figure 1—Attenuation of Potential Change, Line Current and Cathodic Current Density, with distance along line from a single drainage point.

Figure 1 shows the three basic attenuation equations, for potential, current on structure, and cathodic current density, all plotted against distance from a single drainage point, for a line with the following characteristics:

Pipe: 8⅝ inches OD, 22.36 lbs. per ft.; $R_S = 0.00965$ ohm per kilofoot.
Coating: None.
Soil: $\rho = 600$ ohm-cm; $R_L = 0.050$ kilofoot ohm.

$$R_K = \sqrt{R_S R_L} = 0.022 \text{ ohm}$$
$$R_G = \tfrac{1}{2} R_K = 0.011 \text{ ohm}$$
$$\alpha = R_S/R_K = \sqrt{R_S/R_L} = 0.439 \text{ per kilofoot.}$$

If this were a coated line, the potential at the drain point would be limited to a maximum of 2.5 volts negative, measured with reference to a standard copper-sulfate electrode. The same limit is used here in order to obtain comparable results. Assuming the normal pipe-to-soil potential to be 0.6 volt, we have

$$V_o = 1.9 \text{ volts}; \quad V_x = 1.9\, e^{-.439x} \qquad [1]$$
$$I_o = V_o/R_K = 86.4 \text{ amp}; \quad I_x = 86.4\, e^{-.439x} \qquad [2]$$
$$i_o = 16.7 \text{ ma/sq. ft.}; \quad i_x = 16.7\, e^{-.439x} \qquad [3]$$

If 0.85 volt is used as a criterion for protection, it can be interpolated from the curve, or calculated

from [1], setting $V_x = 0.25$, that this is achieved as far as $X = 4.62$; i.e., a rectifier draining 172.8 amperes from the line would fully protect $2 \times 4620 = 9240$ feet of line. Partial protection would be had for a considerable distance beyond, however; and if the entire line is to be protected, units could be spaced so that at each mid-point each of the two adjacent units would contribute just half the required potential change. Solving [1] for $V_x = 0.125$, $X = 6.20$ is obtained. Thus an indefinite length of this line can be placed under full protection by draining 172.8 amperes from each of a series of points spaced 12,400 feet apart; the average current demand will be 73.5 amperes per mile.

If there are to be 172.8 ampere drainage points distributed along the line at intervals of 12,400 feet, then it would appear from the principle of superposition that some contribution to the potential might be made from the two units located $3 \times 6200 = 18{,}600$ feet from each midpoint. From equation [1] $V_x = 0.00053$; so the effect of these distant units is negligible.

There is an obvious loss of power involved in lowering the potential at the drainage point by the unnecessarily high value of 1.9 volts; not so obvious at first glance is the 164 watt I^2R loss in the pipe itself—6 percent of the total output, assuming a 15-volt rectifier. A saving in current is to be expected, then, if smaller units are used at closer spacing; say, 80 amperes each instead of 175.

$$I_A = 80 \text{ amp.}; \; I_o = 40 \text{ amp.}; \; I_x = 40\, e^{-.439x} \qquad [2a]$$

$$V_o = I_o R_K = I_A R_G = 0.88 \text{ volt}; \; V_x = 0.88\, e^{-.439x} \qquad [1a]$$

$$i_o = 7.65 \text{ ma/sq. ft.}; \; i_x = 7.65\, e^{-.439x} \qquad [3a]$$

Again setting $V_x = 0.125$ volt, from equation [1a] the result is $X = 4.46$. We shall have 80 ampere units at a spacing of 8920 feet, giving an average current demand of 47.4 amperes per mile. The I^2R loss in the line has now dropped to only 35 watts, and any further reduction in unit size will make it shrink rapidly. Looking again at the contributions by more distant units, we find, by setting $X = 3 \times 4.46 = 13.38$, from equation (1a), $V_x = 0.0025$; the total contribution by the two adjacent units is now 0.005 volt, which is not entirely negligible. At still closer spacing we shall expect still more important contributions, not only from the two units immediately adjacent, but from others more distant; but these effects can best be exhibited by a further development of the equations.

Consider a series of equally spaced drainage points, each draining I_A amperes from the line to remote earth. Let the uniform distance between successive drainage points be 2m kilofeet. Then at a mid-point we shall have a potential change of

$V_{m1} = 2V_o e^{-\alpha m}$, from the two stations immediately adjacent,

$V_{m2} = 2V_o e^{-3\alpha m}$, from the next two,

$V_{m3} = 2V_o e^{-5\alpha m}$ from the next two, and so on. Finally,

$$V_m = 2V_o e^{-\alpha m} + 2\, V_o e^{-3\alpha m} + 2\, V_o e^{-5\alpha m} + \ldots .$$

$$= 2\, V_o \, (e^{-\alpha m} + e^{-3\alpha m} + e^{-5\alpha m} + \ldots)$$

$$= V_o \operatorname{csch}(\alpha m), \text{ or}$$

$$V_m = \frac{V_o}{\sinh(\alpha m)} \qquad [4]$$

The latter form is more convenient, since tables of the hyperbolic sine are more readily available than those of the cosecant. As we may wish to assign values to I_A and solve for m, we shall also use

$$\sinh(\alpha m) = V_o / V_m = I_A R_G / V_m \qquad [5]$$

The results of applying these two equations to the line already discussed are tabulated in Table I, and shown graphically in the upper curve of Figure 2. Note that the newly derived expression gives a spacing of $2 \times 6.21 = 12{,}420$ feet as compared with 12,400 and an average current demand of 73.4 amperes per mile as compared to 73.5 obtained without consideration of additional drainage points. When we go to the 80-ampere units, the difference is more pronounced; the spacing is 9000 feet as compared to 8920, and the current demand is 47.0 amperes per mile as compared to 47.4; for still smaller units the

TABLE I

Pipe: 8⅝" OD, 22.36 lb./ft.; $R_S = 0.00965$ ohm per kilofoot.
Coating: None
Soil: $\rho = 600$ ohm-cm.; $R_L = 0.050$ kilofoot ohm.
$R_K = 0.022$ ohm; $R_G = 0.011$ ohm
$\alpha = 0.439$ per kilofoot
Maximum $V_o = 1.9$ volt; minimum $V_m = 0.25$ volt
$I_{avg.} = 26.4$ amperes per mile (limit)

I_A Amperes	V_o Volts	$\sinh(\alpha m)$	αm	m Kilofoot	$I_{avg.}$ Amperes per Mile
172.8	1.900	7.600	2.726	6.21	73.4
80	0.880	3.520	1.971	4.50	47.0
40	0.440	1.760	1.331	3.04	34.8
20	0.220	0.880	0.794	1.809	29.2
10	0.110	0.440	0.427	0.975	27.1
5	0.055	0.220	0.218	0.498	26.5
2.5	0.0275	0.110	0.110	0.250	26.4
1.25	0.0138	0.055	0.055	0.125	26.4

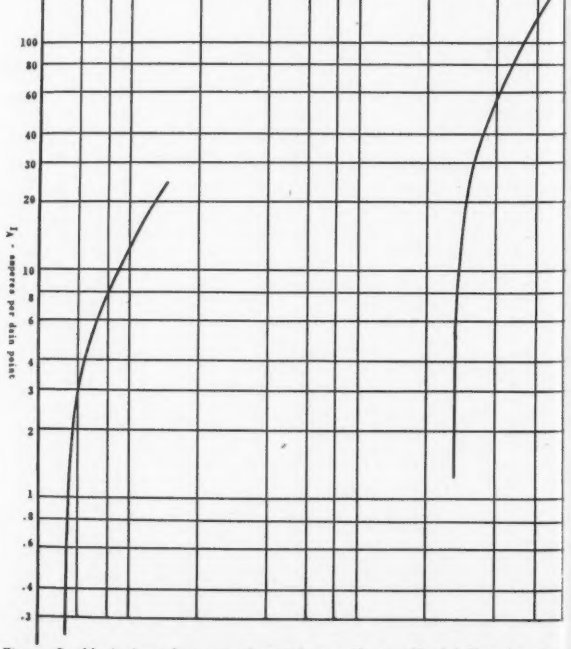


Figure 2—Variation of current demand per mile to afford full protection, plotted against current drained per drainage point. Upper curve: Bare 8-inch line in low resistance (600 ohm-cm.) soil. Lower curve: Same line in same soil, with coating equivalent to 2 percent bare.

difference is more pronounced. Finally, if we try units smaller than 10 amperes (on this particular line) we are apparently unable, by using only the original equations, to obtain full protection even at the drainage point. Only by considering the combined effects of several drainage points are we able to get a true picture of the protection which we know can be installed on such a line, as with the use of magnesium anodes.

The current demand decreases rapidly with the initial decrease in current per drainage point, but soon approachs a limit, as may be seen from the fact that for small values of m, sinhαm is substantially equal to αm. By actually equating them, we obtain

$$I_{avg.} = (5.28\alpha^2/R_S)V_m, \text{ or} \quad [6]$$

$$I_{avg.} = (5.28\ V_m/R_L) \quad [7]$$

Equation [6] is a useful form in determining current requirements for a line which has been tested in such a way as to determine the attenuation constant, α. Equation [7] is merely Ohm's law; it states that the current demand is that current required to produce the desired potential drop across the leakage resistance. This is true, of course, only in the limit; that is, for values of m small enough that sinh (αm) $= \alpha$m for all practical purposes. The value of m for which this is true varies widely for different lines.

Table II shows the same calculations for a similar line in the same soil, but considered as covered with a protective coating having a conductivity corresponding to 2 percent bare. The variation of current demand with unit drainage point size is shown for this line in the lower curve of Figure 2. It will be seen that for the coated line, the limit is substantially attained at lower values of current, but at larger values of m.

For the coated line, the maximum value of current that can be drained from a single point without exceeding the potential limit is only 24.4 amperes. In spite of this much smaller current, the greater length of pipe involved is such that the I^2R loss is 92 watts, or about 24 percent of the total power delivered to the line by the rectifier.

The values computed by equations [6] and [7] are subject to greater distortion by non-uniformities than are the simple attenuation equations on which they are based. R_S alone of the quantities involved may be expected to be uniform, and, because the results from these two equations are ideal values, any variation encountered will probably have the effect of increasing the current demand.

One method of application is the determination of α from a test or tests run with a generator or storage battery, and a temporary ground bed. If the test is reliable, equation [7] will yield the ideal minimum current which may be expected to protect the line. In order to approach this ideal minimum, it will be necessary to maintain uniformity in the size and spacing of stations; variations needed to match the terrain, to fit available sites, and the like, will tend to increase the demand; furthermore, the "natural" or unprotected potential of the line will be variable, and additional current will be required to protect the worst sections. The actual current consumed in a finished installation will vary from the values predicted by the equations by a factor ranging from 1.10 for the most favorable conditions to perhaps 3.0 for the worst.

The foregoing discussion shows that a given pipeline may be placed under protection at a maximum *current* economy by the use of a large number of relatively small drainage points; that the minimum of current consumption may be reached without the necessity of supplying continuous drainage — the spacing may be as great as two miles on a well coated line without exceeding the theoretical minimum current by more than 5 percent; it is without the scope of this paper to complete the analysis by showing that such small drainage points may be installed at

TABLE II

Pipe: 8⅝" OD, 22.36 lb./ft.; R_S = 0.00965 per kilofoot
Coating: Fair—equivalent to 2 percent bare
Soil: ρ = 600 ohm-cm.; R_L = 2.5 kilofoot-ohms
R_K = 0.155 ohm; R_G = 0.078 ohm
α = 0.062 per kilofoot
Maximum V_o = 1.9 volt; minimum V_m = 0.25 volt
$I_{avg.}$ = 0.525 ampere per mile (limit)

I_A Amperes	V_o Volts	sinh(αm)	αm	m Kilofoot	$I_{avg.}$ Amperes per Mile
24.4	1.900	7.600	2.726	44.0	1.46
16	1.248	4.992	2.319	37.4	1.13
8	0.624	2.496	1.645	26.5	0.796
4	0.312	1.248	1.046	16.85	0.626
2	0.156	0.624	0.589	9.50	0.555
1	0.078	0.312	0.307	4.95	0.534
0.5	0.039	0.156	0.155	2.505	0.526
0.25	0.0195	0.078	0.078	1.258	0.525

TABLE III

Pipe: 8⅝" OD, 22.36 lb./ft.; R_S = 0.00965 ohm per kilofoot
Coating: Fair to poor
Soil: ρ = 100-400 ohm-cm
Attenuation (from plotted V_x) α = 0.114 per kilofoot
Potential required to raise observed pipe/soil potentials to 0.85 volt minimum V_m = 0.26 volt
$I_{avg.} = (5.28\alpha^2/R_S)V_m$ = 1.85 amperes per mile
1.85 x 105 % = 1.94 amperes per mile anticipated current demand
Optimum spacing: m $0.54/\alpha$ = 4.73
spacing = 2m = 9460 feet

$$\text{Current per station} = 1.94 \times \frac{9460}{5280} = 3.48 \text{ amperes}$$

Actual average spacing used	3610 feet
Actual average current per station	1.60 amperes
Actual average current per mile	2.28 amperes/mile
Attained factor of prediction	2.28/1.94 = 1.18

This line might have been more economically protected by the use of larger stations at somewhat greater spacing.

TABLE IV

Pipe: 8⅝" OD, 22.36 lb./ft.; R_S = 0.00965 ohm per kilofoot
Coating: Fair
Soil: ρ = 200-1100 ohm-cm
Attenuation (from plotted V) α = 0.0588 per kilofoot
Potential required to raise observed pipe/soil potentials to 0.85 volt minimum: V_m = 0.26 volt
$I_{avg.} = (5.28\alpha^2/R_S)V_m$ = 0.492 amperes per mile
0.492 x 105% = 0.516 amperes per mile anticipated current demand
Optimum spacing: m = $0.54/\alpha$ = 9.20
spacing: = 2m 18,400 feet

$$\text{Current per station} = 0.516 \times \frac{18{,}400}{5280} = 1.72 \text{ amperes}$$

Actual average spacing used	8820 feet
Actual average current per station	1.81 amperes
Actual average current per mile	1.06 amperes/mile
Attained factor of prediction	1.06/0.516 = 2.05

It is believed that the current requirement test on which the attenuation factor was based was not run on a typical section of the line; in the vicinity of the test site, the actual current applied was about 0.6 amperes per mile, giving a prediction factor of 1.16.

costs per ampere comparable with the larger ones typical of rectifier installations. Other studies have been made, and are in the process of being made, which show that, by the use of expendable anodes of magnesium, current may be drained in small units at costs comparable with the larger drains associated with rectifiers.

To illustrate the degree of conformity with the equations which may reasonably be expected, two examples may be given of lines which were tested by means of generators and temporary ground beds, and which were subsequently placed under full protection by means of magnesium anodes. The data are presented in Tables III and IV. The "optimum spacing" listed was determined by arbitrarily assuming that an economic balance between absolute minimum current demand and reasonable installation costs could be obtained by adopting a value of $\alpha m = 0.54$; at which value $\sinh(\alpha m)$ is 5 percent greater than αm itself. It is not claimed that this will be the economic balance for all lines encountered; the factors of accessibility, proximity to roads, avoidance of cultivated fields, etc., are much too variable to permit an accurate paper solution. In addition to these factors, it is frequently necessary to vary the spacing widely in order to take advantage of low resistivity soil, to protect short-circuited casings, and take care of other local conditions.

In short, the mathematical analysis here presented is intended to present a picture of the relations involved, rather than to serve as design formulae; for the extremely complex problem of cathodic protection there is as yet no adequate substitute for experienced field design.

References

1. Robert Pope, Corrosion **2**, 307-319 (1946) Dec.
2. J. M. Standring, Corrosion **3**, 301-309 (1947) June.
3. M. E. Parker, Corrosion **3**, 151-154 (1947) April.

TECHNICAL PAPERS UNDER REVIEW OR BEING CONSIDERED FOR EARLY PUBLICATION IN CORROSION MAGAZINE

Insulated Joints—By Dr. W. Beck, Department of Metallurgical Engineering, Lehigh University, Bethlehem, Pa.

A Cooperative Approach to Electrolysis Problems—By R. L. Lawall, American Telephone and Telegraph Co., Detroit, Mich.

Corrosion, Passivity & Passivation from the Thermodynamic Point of View—By M. Pourbaix, Journees des Etats de Surface, Paris, France.

Corrosion Problems in a Modern Fluid Catalytic Cracking and Fractionation Unit—By Nathan Schofer, Cities Service Refining Corp., Lake Charles, La.

Current Intensities of Soil Corrosion Cells—By E. D. Sunde, Bell Telephone Laboratories, New York, N. Y.

Organic Linings for Chemical Equipment—By Kenneth Tator, Chemical Engineer, Coraopolis, Pa.

Geographic Study of Deposits and Corrosion—By F. N. Alquist, Organic Research Laboratory, The Dow Chemical Co.

Unusual Corrosion in High Pressure Boilers—By S. T. Powell and L. G. Von Lossberg, Chemical Engineers, Baltimore, Md.

A Case of Corrosion Involving Cinders—By C. H. Thompson, New York Telephone Co., New York, N. Y.

Crude Still Overhead System Corrosion—By A. F. Blumer, Esso Standard Oil Co., Louisiana Div., Baton Rouge, La.

Corrosion Problems in the Manufacturing of Sulfuric Acid—By T. L. Hart, National Zinc Co., Bartlesville, Okla.

Steam Reboiler Corrosion—By W. S. Janssen, Pan American Refining Corp., Texas City, Texas.

Galvanic Corrosion in Oil and Gas Well Fluids—By F. L. LaQue, International Nickel Co., New York, N. Y.

Value of Backfill With Carbon and Graphite Anodes—By J. P. Oliver, National Carbon Co., Cleveland, Ohio.

Mitigation of Corrosion on City Gas Distribution Systems—By A. D. Simpson, Jr., United Gas Corp., Houston, Texas.

Preliminary Evaluation of Resinous Coatings—By W. R. Smith, Nukem Products Corp., Buffalo, N. Y.

Electrolysis Experiences on 115 KV High Pressure Oil-Filled Pipe Type Cable Installation in New Orleans—By S. E. Trouard, New Orleans Public Service, New Orleans, La.

Microscope As An Aid in Corrosion Problems—By H. M. Wilten, The Texas Company, Port Arthur, Texas.

Topic of the Month

ALUMINUM VALVE CONSTRUCTION

By R. McFARLAND*

Aluminum ordinarily is not considered a valve material. However, a number of wrought and cast aluminum alloys have very satisfactory corrosion resistant and physical properties, and for this reason they lend themselves readily to the construction of valves. One benefit accruing from the use of aluminum alloys is the great weight saving that can be accomplished. In fact, on one recent valve project the entire valve assembly in aluminum alloy weighed less than the entire valve assembly fabricated from No. 10 and No. 12 gauge stainless sheet.

A recent application involved the selection of all-aluminum diaphragm valves in a chermurgic process wherein the valves were to handle abrasive materials in suspension in an atmosphere contaminated with fumes of sulfurous and low molecular weight organic acids. In some instances the valves also were required to handle solutions of sulfurous acids containing low molecular weight organic acids.

The specifications required that the valve be of very light weight, yet sufficiently strong from a structural standpoint to resist pipe strain, distortion and strains from remote control valve operation.

The structural requirements were satisfactorily met with Alcoa 43 or 356 alloy for the body, bonnet, compressor, and valve handwheel. The valve stem and sleeve were of stainless steel and bronze sleeve material, respectively, with these working parts separated from the aluminum by high strength plastic bearings in order to provide lubrication, smooth operation, and nongalling with the main aluminum parts.

The valve bodies were satisfactorily rubber lined in one case with soft abrasion-resisting rubber and in another with specially compounded Ebonite for maximum resistance to the highly destructive sulfurous acid.

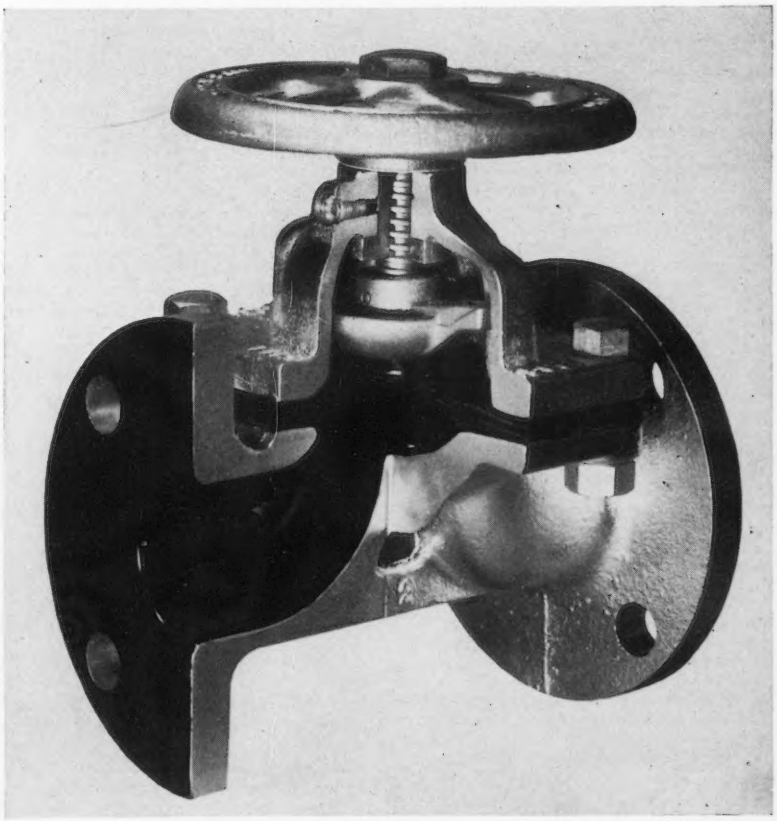
The valve bonnet parts were satisfactorily protected from atmospheric corrosion by properly coating with a heat hardenable phenolic resin as a safeguard against the possible corrosion of the aluminum bonnet parts through contact with a sulfurous acid-contaminated atmosphere or inadvertent splashing of these valve parts by process liquors.

The phenolic coating on aluminum was field tested through suspension samples installed in the top vapor head of a distillation column handling the acid liquors of sulfurous acid and low molecular weight organic acids. At the end of six months' test, the aluminum samples and their phenolic coatings were unaffected by this service.

An all-aluminum valve of the same design has found satisfactory application in gasoline loading rack service, wherein it was desired to secure a valve that was rustproof, light in weight, unaffected by pipe strain or distortion, easily serviceable, and tight seating with the elimination of stuffing box leakage.

Small size valves of similar design also have been found very satisfactory in use in small high-speed combat craft, wherein these valves were utilized to handle gasoline and distilled water. In this case, because of the possibility of salt-water corrosion, a sacrificial material was included in the interior of the bonnet assembly to protect galvanically the aluminum bonnet parts from air and salt-water corrosion.

Alcoa 356, or 43 alloy, also has been extensively used in this valve design for distilled water service in laboratory installations as well as in large industrial distilled water apparatus. The silicon aluminum alloys have not contaminated the distilled water in these all-aluminum systems, with the result that expensive block tin, pipe, pipe fittings, and valves have been eliminated in these installations. It might be mentioned that Alcoa B-214 alloy also has been used as a valve construction material for distilled water service; however, its use has been supplanted by Alcoa 43 or 346 alloy because of the ease of procurability, high strength, and satisfactory corrosion resistance of these latter alloys.



Phenolic-lined aluminum valve.

* Technical director, Hills-McCanna Company, Chicago, Illinois.

NACE News

Conference Program Developing Fast

Active work by NACE committees on the program for the 1949 conference in Cincinnati, April 11-14, has brought a number of developments during the past several weeks. Eleven symposia, two of which cover subjects of general application and nine devoted to problems of special industry classifications, have been outlined. In some cases all technical papers for some symposia have been arranged for, and in all cases, completed arrangements are near.

Fifty-five exhibitors will display the latest equipment and materials used in corrosion control at the Netherland Plaza exhibition rooms. In addition, the National Bureau of Standards is contemplating an exhibit and the NACE itself has under consideration a display of its activities. All available exhibit space has been sold, evidencing the interest industry has in the work of the association.

Current classification of exhibitors is as follows: Chemical inhibitors, 1; protective coatings, 5; corrosion-resistant materials, 7; cathodic protection, rectifiers and equipment, 7; galvanic anodes, 4; pipe line wrapping and equipment, 7; pipeline and cathodic protection and service organizations, 7; protective coatings (pipe line), 7; instruments and inspection, 4; grease and oils, 1; ceramics and transite, 2; communications, 1; miscellaneous, 2.

Another feature believed to have considerable value and interest is the program of continuous motion pictures on pertinent topics which will be presented in the hotel's Julep Room. Members and visitors will have the opportunity to see the latest films on corrosion topics during the convention.

Social events already arranged or under consideration include a banquet and a friendship hour.

The schedule of symposia has been given as follows: Corrosion Principles, Cathodic Protection, Chemical Industry, Electrical and Communications Industries, Gas Industry, General Industry—Rust preventives, coatings, corrosion, boilers, machine tools, erosion; Oil Industry, Pulp and Paper Industry, Protective Coatings, Salt Water, Transportation Industry.

Papers to be given under the various subdivisions will represent an exposition of the latest available technical and practical information on their respective topics. Abstracts already available indicate subjects will be covered exhaustively.

Exhibitors are preparing to put on display for inspection by conference members the latest devices and materials available for corrosion control. Informed and well-posted personnel at each booth will be available to answer questions and extend information.

Industry exhibits at previous conferences were considered by many to be one of the most valuable features of the conference in that they gave the interested an opportunity to see and compare at one time, the various devices and materials being developed for the control of corrosion. The 1949 conference is expected to be even more valuable in this respect than in former years because of the intense efforts manufacturers have been making to develop new means to fight corrosion.

Exhibitors also find conference time valuable in that it gives them an opportunity to hear first hand some of their customers' problems.

Committees working on the details of the 1949 conference believe arrangements this year will reach a new high in efficiency and that the fact all activities are to be under one roof at the Netherland Plaza will meet approval of all attending.

Northeast Region and Philadelphia Section of NACE held an all-day joint meeting December 2 at Philadelphia Engineers Club, 1317 Spruce Street, Philadelphia. Talks on a practical method for combatting anaerobic bacterial activity entitled, "Environmental pH as a Factor in Control of Anaerobic Bacterial Corrosion," by J. B. Hunter, H. F. McConomy and R. F. Weston, of Atlantic Refining Co., Philadelphia; a discussion on a non-metallic material, "Fiberglas Laminates, Their Physical properties and Resistance to Corrosion," by Dr. R. J. Nebesar of Universal Moulded Products Corp., Philadelphia and the film, "Walls without Welds," depicting fabrication of seamless tubing by G. W. Webster and T. E. Conlon of the National Tube Co., Philadelphia constituted the program.

Membership cards now are available to all members of the National Association of Corrosion Engineers in good standing. They will be supplied only on request. In applying for the cards members are asked to write clearly their names and addresses. The card, printed in green, contains the NACE emblem, name of the member, expiration date and signature of the executive secretary.

CORROSION PROBLEMS

Questions and Answers for this section should be submitted to L. G. Vande Bogart, Crane Co., Engineering and Research Division, 836 S. Michigan Ave., Chicago, Illinois. All questions will become property of NACE. Those not printed will be answered by mail. Questions should carry sufficient detail to describe the problem. Answers to printed questions are solicited. Authors of questions will remain anonymous to readers, while authors of answers may remain anonymous by request.

No. 1—In some oil wells in which hydrogen sulfide is present in the gas; intense corrosion of steel is noted. In other wells with the same hydrogen sulfide concentration there appears to be decidedly less corrosion. What explanation can be offered for this?

No. 2—What is responsible for corrosion of boiler blow-down piping by concentrated boiler water which is not corrosive within the boiler and which does not yield a corrosive steam or a corrosive condensate? Corrosion takes the form of pitting at breaks in a corrosion scale and has the appearance of oxygen concentration cell attack.

No. 3—Should accelerated corrosion be expected at a break in a baked-on non-metallic coating on steel (steel pipe) exposed to a chloride solution: a) Aerated? b) Air free?

No. 4—How should commercial aluminum alloys be listed with regard to susceptibility to stress corrosion cracking in fresh water and in salt water?

No. 5—What are the qualifications a metal should have in order for it to be a satisfactory galvanic anode?

No. 6—In condensate wells carbon dioxide is considered to be the corrosive agent. What is the corrosion mechanism in this case?

No. 7—When a well tubing made of a comparatively noble material is used with a casing made of less noble material 1) can the casing be protected from possible galvanic corrosion from the noble tubing by installing galvanic anodes: a) on the outside of the tubing? b) in the annular space in a mud used to fill the space?

Houston Section NACE held a joint meeting with the Houston unit of the American Society of Mechanical Engineers at Bill Williams' Chicken House, Monday, November 15. "General Corrosion," an illustrated talk, was given by Monroe Shigley of Dow Chemical Co. Mr. Shigley discussed corrosion problems encountered in the Gulf Coast region and steps that have been taken to solve them. Guests included Prof. George H. J. Thompson, Texas A. & M. College, chairman South Texas Section ASME. The Houston Section, because of the Christmas season, will hold no meeting in December but will meet in January.

The Southeast Region of NACE held its fall meeting in Atlanta November 29 at an afternoon and dinner session with 35 members present. Dr. I. A. Denison, Underground Corrosion Section, National Bureau of Standards, presented a travelog covering the fifteen Bureau of Standards test sites. His discussion covered types of soil encountered and relative corrosion rates for numerous materials under test at each location. He also discussed fundamental aspects of various criteria for determining extent of cathodic protection.

Dr. James T. MacKenzie, American Cast Iron Pipe Company, led a discussion on electrolysis and the experience with the application of cathodic protection. These problems were discussed in relation to oil, gas, and water pipe lines and telephone cables.

Juan Rios, Cuban Telephone and Telegraph Company, Havana, Cuba, presented an interesting discussion on "Corrosion Problems in Havana."

The meeting closed with a short business session.

The nominating committee consisting of Jack Adams, Southern Natural Gas Company, chairman; Paul Boyd, Georgia Power Company, and A. R. Swanson, A. T. and T., submitted the following slate of officers to be voted on for the coming year: E. C. Range, Okonite Corporation, chairman; J. W. Yeldell, Southern Natural Gas Company, vice chairman, and E. D. McCauley, American Cast Iron Pipe Company, secretary. Tentative plans for a spring meeting early in March were completed. This is to be an all day conference ending in a joint dinner meeting with the American Society of Metals and NACE with F. L. LaQue as dinner speaker.

"Combatting Corrosion with Paint," an address by Dr. George Diehlman of the National Lead Company was the feature of a joint meeting of the Northeast Region and the Metropolitan New York section of NACE December 2. The talk covered practical application of paint to structures exposed to normal and marine atmospheres.

Election of officers was scheduled at the December 7 meeting of the San Francisco Bay Area Section NACE at the P.G.E. Auditorium, Oakland. W. J. O'Connel, Jr., consulting engineer gave a talk on "Inter-relation Between Microbiological Deposits and Corrosion." A corrosion clinic was held also.

PREPARING MANUSCRIPTS FOR PUBLICATION

(In One Easy Lesson)

(Following is a short outline for the information of authors preparing manuscripts for publication in CORROSION).

I. Mechanical

A. It is desirable to have manuscripts typed, double-spaced on one side of the paper, leaving a margin of at at least one inch all around.

B. Normally three copies of each manuscript are required. In most cases it will be satisfactory to supply only one copy of figures suitable for reproduction.

C. Pages should be numbered consecutively from front to back.

D. All Figures should be numbered consecutively as they are referred to in text.

E. All tables should be numbered consecutively as they are referred to in text.
   1. Where practical, it is desirable to have tables and illustrations on pages separate from text.

F. References should be indicated in text with superior figures, or numbered consecutively as they occur in text. They should be collected in order of their occurrence on a separate sheet becoming the last page of the manuscript.

G. Photomechanical reproduction processes requiring a decrease or increase in size of original figures make it mandatory that the copy for figures be clear and capable of the required alteration. In most cases original drawings, tracings, photographs are necessary to get proper reproduction. Drawings in black ink on white paper reproduce best.

H. Sufficient identification always should be given in compiling a discussion or the answer thereto so that they may be properly added to the manuscript to which they refer.

I. When duplicated copies are supplied for printing, *each copy* should be inspected for illegibility, and illegible portions clarified.

II. Editorial

A. All copies of manuscripts consisting of a verbatim transcript of an orally-delivered paper normally will require extensive editing.
   1. Preferred person is third.
   2. Tense should be same throughout.
   3. Subdivisions and their indices should be consistent.
   4. Delete or modify all references to matter used in oral presentation and not included in manuscript for publication.

B. Make editorial corrections legible. Use a soft black pencil. If extensive corrections, additions or changes are necessary it is desirable to write the matter on separate sheets and indicate as inserts.
   1. Standard proofing marks may be found in the appendix of unabridged dictionaries.
   2. Correct all copies.
   3. Check the accuracy and completeness of all references.
   4. Be sure captions and cut lines for figures and tables are correct and complete.

REVIEW—When all this has been achieved, carefully review the manuscript, checking each point to be sure that all have been covered.

PERSONALS

Dr. I. A. Denison, Underground Corrosion Section, Bureau of Standards, is completing his biannual trip removing soil test specimens from the fifteen sites. Dr. Denison reports that he has had very pleasant contacts with NACE members throughout this trip. Ten members and interested parties were present at the test site in Atlanta when the specimens were removed on Saturday, November 27. It was apparent that Atlanta's site is one of the least corrosive areas.

Juan Rios, Cuban Telephone and Telegraph, Havana, Cuba, came to Atlanta November 28 for the South Central Regional meeting. During his short stay he is conferring with the telephone people on cable corrosion problems. Mr. Rios is the only member of NACE in Cuba.

Henry Allen, formerly with The Dow Chemical Company has joined the staff of Cathodic Protection Service and will have his headquarters in Houston. The firm has moved to its new permanent location at 1801 Bissonett.

F. M. Hieronymus, Barret Division, Allied Chemical and Dye Corporation representative in the Corpus Christi, Texas area has been transferred to the Tulsa, Oklahoma area by his firm.

Walter C. Bates and **Dr. George F. Rugar** will be manager and assistant manager respectively of Diamond Alkali's new technical service division.

S. L. Neevins has been named general manager of Mathieson Chemical Corporation's newly formed ammonia department.

Francis C. Frary, director of research, Aluminum Company of America, New Kensington, Penna. has been elected to receive the gold medal of the American Society for Metals for 1948, for outstanding metallurgical knowledge and versatility of application of science to the metal industry.

G. E. F. Lundell, for many years head of division of chemistry, National Bureau of Standards, has retired.

BOOK REVIEWS

PREVENTION OF IRON AND STEEL CORROSION: "Processes and Published Specifications" by C. Dinsdale, M. Sc., F.I.M. Published October 25, 1948 (postage 3d) by The Louis Cassier Co. Ltd., size D8vo (8¾" x 5½")—67 pages. Cloth bound with jacket.

This book is an attempt to compile a complete index of processes and published specifications relating to the prevention of the corrosion of iron and steel, and the standard specifications connected therewith.

The matter is divided into three parts: Methods of preventing corrosion (broken down into eleven groups), cleaning metal parts and codes of practice. Two appendices deal with authorities issuing specifications and with paint and paint component specifications.

The author has had the cooperation of the Ministry of Aircraft Production, Armament Research Department (Woolwich), British Standards Institution, B.I.S.R.A. Corrosion Laboratory, Research Association of British Paint, Colour and Varnish Manufacturers, British Cast Iron Research Association, D.S.I.R. Chemical Research Laboratory, etc.

STRESS-CORROSION TESTS ON HIGH-STRENGTH ALUMINUM ALLOY SHEET. By Hugh L. Logan and Harold Hossing. 18 pp. Supt. Documents, Washington 25, D. C., 15 cents.

Report on stress-corrosion tests of high-strength aluminum alloy sheet. Materials investigated were 24S-T, aged 0 to 12 hours at 375° F; R301-T; bare and clad 75S-T; bare and clad R303-T275; and bare and clad R303-T315 alloys. These materials were exposed unstressed and stressed in tension to three-quarters of the yield strength in a sodium chloride-hydrogen peroxide solution and in a marine atmosphere. Zinc-bearing alloys, 75S-T and R303-T also were exposed, while stressed by bowing, in a boiling 6 percent sodium chloride solution. Corrosion damage was evaluated from losses in tensile strength and elongation. Commercial 24S-T material, aged four hours or longer, and other alloys supplied by the manufacturers, with the exception of R301-T alloy, were resistant to stress-corrosion cracking.

PUBLICATIONS OF THE NATIONAL BUREAU OF STANDARDS. Circular 460. Supt. of Documents, U. S. Government Printing Office, Washington 25, D. C., 75 cents.

Listing all Bureau publications from 1901 to June 30, 1947. Brief abstracts of publications issued from January 1, 1942 to June 30, 1947 also are included.

TECHNICAL DATA BOOK—Phosphor Bronze Corp., 2200 Washington Ave., Philadelphia 46, Penna. No charge.

Sections cover phosphor bronze strip and sheet, wire, rope, castings, bushings and ingots. Tabular data includes physical properties, chemical analyses, special spring design and machinability data.

NEW PRODUCTS

Materials – Service – Literature

Modern coating and wrapping of small diameter steel pipe will be done at the 70,000-square-foot plant of Standard Pipeprotection, Inc., 3000 S. Brentwood Blvd., St. Louis, Mo., which began operations this month. Cost of the plant, and its 20-acre site is given as $500,000. Plans for expansion of the Brentwood plant and construction of two other plants in the Southwest are being made. George B. McComb, Summit, N. J. is president, Hugh W. Baird, Evanston, Ill., vice-president and John B. Wilson of Tenafly, N. J., secretary-treasurer. All officers formerly were with Barrett Division, Allied Chemical and Dye Corp., N. Y.

Iron Oxide as electrical insulators between iron laminations of generators and motors are being used by Westinghouse Electric Corp. Oxides formed above 570° C. have low resistance because FeO formed at this temperature subsequently decomposes into free iron and Fe_3O_4. Lack of uniformity was overcome by a new process of steam oxidation in which annealing and oxidation processes were combined. The electrical sheet steel was placed in a heat-treating furnace, annealed and then brought down below 570° for the steam oxidation. The coating formed is moisture and burnout proof, the company claims, and provides a good base for finishing operations.

"Quinterra." a new, inorganic, asbestos-base flexible sheet now is being produced by Johns-Manville. The sheet is intended for use as electrical insulation and can be made from 1.5 mil to 20 mils thick. Manufacturers say the material, which is of closed structure, and has the general appearance of paper, has high dielectric strength of well over 250 vpm even at high temperatures. It is being supplied in long lengths in roll of tape form in thin gauges for electrical wire insulation and slightly thicker for layer insulation.

Zinc rods, fitted with standard pipe-plug ends designed to screw into heat exchangers, piping and other hydraulic equipment to provide corrosion protection are being manufactured by Rotometals, Inc., 980 Harrison St., San Francisco 7, Cal. The rods, called "Cor-ins" are made in ⅜-inch, ½-inch, ⅝-inch, ¾-inch and 1-inch diameters and in lengths up to 12 inches. The manufacturers claim the rods extend the protection of galvanizing, extend life of installations in which corrosion conditions do not seem severe and appear to have a basic application in systems subject to deterioration because of electrolytic action. Non-exclusive distributorships are available.

Gerotor May Corp., Baltimore 3, Md. has prepared a 16-page catalog section describing its entire line of air cylinders. Designed to help the engineer lay out air circuits, it is called Section No. 53.

Nondestructive magnetic method for measuring composite copper nickel coatings on steel has been developed by the National Bureau of Standards. The device utilizes two magnets of different strength in conjunction with a set of previously determined calibration curves for each magnet. Accuracy of measurements of total thickness of composite coatings from 0.0005 to 0.003 inch is within about 10 percent. Thickness of component layers can be measured to an accuracy of about 15 percent. Technical details are to be found in "Magnetic Measurements of the Thickness of Composite Copper and Nickel Coatings on Steel," by Abner Brenner and Eugenia Kellogg, J. Research NBS **40**, 295 (1948).

Methly Methacrylate resins have been approved for use in signs in an Underwriters Laboratories' report with approximately the same limitations imposed for wood in similar use.

Powder-actuated driver to pin pipe hangars instantly to concrete or steel is offered by the Mine Safety Appliances Co. The 5-pound tool fires a stud into the surface against which the barrel is pressed. Holding power up to several thousands of pounds is claimed. Complete safety and one-hand, recoilless operation also are claimed.

New series of plastisols and a latex compound designed for high heat resistance applications will be marketed by American Anode, Inc., Akron, Ohio. Manufacturers claim the plastisols will be supplied bubble-free, and may be used for coating metals, wire, pipe lining, wood, textiles and paper. Fire and toxic fume hazards are not present, it is claimed. Articles dipped, coated, sprayed or brushed with the new latex compound are able to resist temperatures as high as 400 degrees F., the manufacturers say.

Fluorine and hydrogen fluoride corrosion of metals at high temperatures is the subject of a 4-page technical report by W. R. Myers and W. B. DeLong of E. I. duPont de Nemours & Co., Inc. The report, offered in reprint form by The International Nickel Company, Inc. 67 Wall Street, New York City details resistance of nickel, monel and other materials to these agents.

Contract for installation of between five and six million pounds of sheet lead, lead pipe and other apparatus at the Garfield, Utah plant of Kennecott Copper Corporation has been let to Andrews Knapp Construction Co., Inc., New York City. Refinery capacity will be 12,000 tons monthly.

Cerro de Pasco Copper Corp. N.Y.C. has named Peck Steel and Die Supply, Los Angeles, Cal., as West Coast distributor for Cerro low-temperature-melting alloys. Anton Peck, proprietor of the California firm, a member of the American Society of Tool Engineers, has had over 20 years experience in the metals and machinery field.

Corrosion Abstracts

COATINGS

Studies on Anti-Fouling Compositions I, II, III. H. Barnes, *BISRA Marine Corr. Sub-comm. Paper MG/BC/48/47* (1947) Aug. 8; *J. Iron & Steel Inst.* **157,** Pt. 4 587-600.

Experiments to determine the weight losses from a graded series of varnish components over two successive 40-day periods when exposed in the sea during the winter. Composition used contained an acid resin and a basic pigment (cuprous oxide). In their preparation, reaction between these two components takes place, copper soaps are formed which are soluble or readily dispersed in the medium. The amount of copper formed in the medium is related to the amount of resin, the cuprous oxide present and to the milling time. Over the first 40 days the loss is proportional to the percentage of resin in the varnish. The presence of inert binders depresses the rate of loss. In the second period (40-80 days) the weight losses were much less and seemed to have no clearly defined dependence on the varnish components. During this period calcium salts become deposited in the film matrix. Losses are due to removal of resin. Acidic material is present in the layers of the film, even after considerable weight losses have taken place. Further study of the role of bacteria in the solution of these films is needed. Tables and graphs. 8 ref.—INCO.

Protective Metallic Coatings on Metals. W. R. Burrow, *Australasian Eng.,* 48-60 (1946) Dec.

A prize essay in the competition conducted by the Melbourne Branch of the Australian Institute of Metals. All the common methods of protection are described. 61 refs.—MA.

Metallizing Takes Over. Edwin Laird Cady, *Sci. Am.,* 201-203 (1947) May.

Metallizing copper heat-exchanger tubes with aluminum and then heat-treating at 1600° F. (871° C.) for 1 hr., imparts better heat-resisting properties to the tubes. The lives of cast-iron pots used for carburizing steel products can be prolonged by metallizing with aluminum. Tests have shown that a sprayed low-carbon-steel bearing surface has better bearing properties than a machined surface of the same steel. The making of dies, moulds, and pans of intricate contours is a rapidly advancing field of metallizing.—MA.

Casein and Soya Bean Protein Glue: Attack by Moulds and Bacteria. C. M. Christensen & C. S. Moses, *U. S. Dept. Agric., Bur. Plant Ind., Soils & Agr. Eng., Forest Path. Spec. Release,* No. 25, 12 pp. (1945); *Exp. Sta. Rec.,* **94,** 742 (1946); *J. Textile Inst.,* **37,** No. 11, A486 (1946); *Packaging Absts.,* **4,** No. 2, 78 (1947).

Two species of penicillium, either alone or working with bacteria, are mainly responsible for mould attack on the protein glues used in plywood manufacture. Sodium trichlorophemate proved effective against both moulds and bacteria, whereas sodium o-phenylphenate was only effective against bacteria. A 2% solution of sodium pentachlorphenate did not weaken the casein glues.—RPI.

Selection of Protective Coatings for Metals. K. G. Compton, Bell Telephone Labs., Paper before Sym. on Modern Metal Protection, Cleveland, Oct. 7, 1947; abstr. *Steel,* **121,** No. 18, 90-91+ (1947) Nov. 3; *Corrosion,* **4,** 112-122 (1948) Mar.; *Canad. Chem. & Process Inds.,* **13,** No. 11, 1027-1030+ (1947) Nov.

Corrosion and physical tests made to determine the suitability of protective coatings for metals described, and instruments used in the Bell Telephone Laboratories are illustrated. Physical tests on organic coatings are more extensive than on metallic coatings, and include tests for hardness, distensibility, abrasion and impact resistance, and adherence to metals. The protective value of various metallic and organic coatings is discussed. Thin coats of zinc or cadmium provide cathodic protection at pores and scratches but are themselves susceptible to corrosion. In an uncontaminated atmosphere with moisture and elevated temperatures, or in salt-fog tests, cadmium gives more protection than zinc. Thicknesses of 0.0005-in. for indoor and 0.002-in. for outdoor exposure are a practical minimum for nickel, tin, copper or chromium coatings. Phosphate coatings on steel have little protective value. Ceramic and organic coatings, enamels and lacquers are also discussed briefly.

Plastics for Insulating and Protecting Instruments from Water or Humidity. W. T. Harris, *Off. Tech. Serv. Report PB. A 53026,* 4 pp. (1944); *N.P.V.L. Abs.,* No. 127, 290 (1947).

A brief discussion of plastic coatings suitable for insulating electrical or acoustic apparatus from water or high humidity, and especially instruments which must be immersed in sea water. The recommended materials are polystyrene and Vinyl resin compns., balata, polyisobutylene, polyethylene, rubber derivs., polyacrylates and phenolic resins.—RPI.

Coating for Eloxal-Treated Light Metals. H. Giehmann, *Off. Tech. Serv. Report PB. L 61958,* 15 pp., (1937); *N.P.V.L. Abs.,* No. 128, 321 (1947).

A number of grease- and enamel-like impregnating materials were tested as to suitability for imparting added corrosion protection to anodically oxidized aluminum. In the case of Eloxal-treated aircraft coverings, the Eloxal layer provides a base for single-coat color enamels which increases the adhesive qualities and durability of the enamel. Data, tables and photographs are included.—RPI.

Surface Protection by Synthetics in the Rayon Industry. K. Friedrich, *Kunstseide u. Zellwolle,* **22,** 2114, (1940); *Peint. Pig. Vernis,* **18,** No. 5, 74D (1943).

Information is given on the use of cellulose ethers, urea and phenolic resins, various other synthetics, and corrosion-inhibiting pigments.—RPI.

German Aircraft Protective Coatings. H. L. Acker, *B.I.O.S., Misc. Report* No. 54, 13 pp. (1945).

Formulae for zinc chrome primers and finishes for aluminum alloys are given. The surface treatment for magnesium was a nitric acid etch followed by soaking in potassium dicloromate and a water rinse. For tail pipes on jet engine exhausts an aluminum heat-resistant paint was used. As sealant for integral fuel tanks an aluminized predoped fabric tape was used, coated on assembly with

Abbreviations at the end of abstracts indicate source of abstract and contributor; and are as follows:

AER	*Aeronautical Review,* Institute of Aeronautical Sciences, Inc.
ALL	*The Abstract Bulletin,* Aluminum Laboratories, Ltd.
AWWA	*Journal,* American Water Works Association
BLR	*Battelle Library Review,* Battelle Memorial Institute Library
BNF	*Bulletin;* British Non-Ferrous Research Association
CALCO	Calco Chemical Division, American Cyanamid Corp.
CE	*Chemical Engineering,* McGraw Hill Publishing Co.
CEC	Consolidated Edison Co. of New York, Inc.
EW	*Electrical World,* McGraw Hill Publishing Co.
GPC	General Petroleum Corp. of California
INCO	The International Nickel Co., Inc.
IP	Institute of Petroleum
MA	*Metallurgical Abstracts,* Institute of Metals, London, Eng.
MR	*Metals Review,* American Society of Metals
NBS	National Bureau of Standards
RA	*Refrigeration Abstracts,* American Society of Refrigeration Engineers
RM	*Revue de Matallurgie,* Paris, France
RPI	*Review of Current Literature Relating to the Paint, Colour, Varnish & Allied Industries,* Research Association of British Paint, Colour & Varnish Manufacturers, London.
TDD	*Technical Data Digest,* Air Materiel Command—Technical Service Section
UOP	Universal Oil Products
No Code	*Current Technical Literature,* Bell Telephone Laboratories

an aluminized acrylic ester. Aerodynamic smoothing is discussed.—RPI.

Zinc Chromate. Zinc Development Assoc., *Z.D.A. Pamphlet*, 3 pp.

A bibliography of 47 refs., but without abstracts, covering the period 1908-1942. —RPI.

Salt Spray Foiled in U. S. A. Zinc Development Assoc., *Zinc Bull.*, **3**, 4-5 (1947).

Metallic zinc/zinc oxygen primers have given good protection over a period of seven years to two steel bridges in the U. S. A.—RPI.

Aluminum-Coated Steel. *Steel*, **120**, No. 13, 80-81+ (1947).

Characteristics and properties of aluminum-coated steel, made by a continuous hot-dip process, are given, with notes on finishing, gas-, arc-, and spot-welding, and brazing (with aluminum alloy brazing rod and flux).—MA.

Plastic Undercoating on Passenger Cars. Anon., *Rail Age*, **26**, 53, (1947); *Rail. Eng. Abs.*, **3**, No. 2, 49 (1948).

Some American railways are experimenting with the spraying of a plastic coating ⅛-inch thick on the underslung parts of coaches such as battery housings and on the bottoms of under-frames and attachments. Application of the plastic coating is expected to afford protection of the metal parts from wear due to ballast particles being sucked up by the train.—RPI.

Anti-Fouling Paints. Anon., *Peint. Pig. Vernis*, **23**, No. 11, 346 (1947).

Zinc-oxide is used, in preference to bentonite, etc., as a diluent for oxide in anti-fouling paints up to 66 percent of the total pigment. Metallic pigments, e.g., zinc and iron powders, exert an inhibitory effect on the toxic properties of copper, but not of cuprous oxide. Zinc powder, however, is the best diluent for mercuric oxide, zinc oxide for mercurous chloride.—RPI.

Protection of Black Iron Roofs at Rabaul, New Britain. Munitions Supply Laboratories (Victoria), *Paint Notes*, **2**, No. 4, 129 (1947).

Two coats of aluminum paint (pigmented with 2½ lbs. per gallon) or two coats of red-oxide roofing paint are suggested for the protection of black iron roofs under tropical conditions and in a sulphurous atmosphere.—RPI.

Paint as Protection for Light Alloys. Anon., *Farg. och Fernissa*, No. 5, (1946); *Paint Manuf.*, **17**, No. 12, 427 (1947).

Permanent elasticity is stressed as an important requirement in paint systems used to protect aluminum and and light alloys. Some unorthodox views on the corrosion of aluminum and magnesium are presented.—RPI.

Condensed Review of Some Recently Developed Materials. Anon., *Machinery*, 169-181, (1947); *Austin Tech. News*, No. 212, (1947).

Tabulated lists arranged alphabetically are given of class or use of material, trade name (American), properties and applications. Among the types of material listed are rust inhibitors and removers, adhesives, degreasers, prepainting solutions and protective coatings.—RPI.

There's More to Good Finishes Than Meets the Eye! *Elec. Manufacturing*, **40**, No. 2, 89-91, 214+ (1947) Aug.

Description of pretreatment or prefinishing compounds that are used on metal surfaces prior to bonding with organic finishes to assure good adhesion and effectively inhibit corrosion, the phosphate-type compounds being the scope of this discussion. Condensed classification of prefinishing methods for preparing metal surfaces for organic finishes is tabulated. Phosphate coatings as corrosion barriers are discussed.—INCO.

Simple Dip Finish. *Die Castings*, **5**, 59-61, (1947) Dec.

Tells how a simple zinc plate followed by a "Unichrome" clear dip produces a clear conversion coating which looks like chromium plate when applied to die castings. The dip treatment forms a clear conversion coating consisting of zinc oxide and zinc chromate, which has the same kind of eye appeal as chromium plate.—BLR.

Protection Against Corrosion. Assoc. Belge Pour L'Etude, L'Essai et L'Emploi des Materiaux, *Chim. Peint.*, **9**, No. 7, 219-25; No. 8, 245-64, (1947).

A report of the Belgian commission for studying the protection of steel by paints. An account is given of the work at various exposure stations and of laboratory investigations in Belgium and other European countries.—RPI.

New Chemical Coating to Protect Metals. Anon., *Chem. Industrie*, **59**, 1001 (1946); *Brit. Abs.* B-II, 298, (1947).

Polyvinyl butyral (100) + H_3PO_4 (30-50 pts.) in Et alc. is brushed or sprayed

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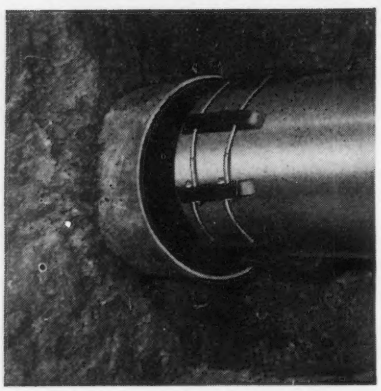

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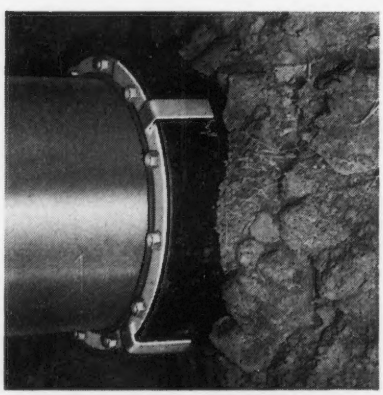

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on to metal surfaces to give a coating which inhibits corrosion (including creeping corrosion) and forms a base to which standard primers adhere tenaciously.—RPI.

Stainless Steel Paint. *Chem. Age,* **57,** No. 1474, 516 (1947); also in *Ind. Fin.,* **23,** No. 12, 11, 131, (1947).

Stainless steel powder, sold in paste form and used in spar varnish, lacquer, or other paint media, protects the surface to which it is applied against acids, fumes and chemicals and has high durability. The material also is available in flake form.—RPI.

Plastic Protective Coatings. Anon., *Chem. Age,* **57,** No. 1482, 722-3 (1947).

Polythene, Thiokol and other thermoplastic high polymers can be applied by flame spray to clean dry metal surfaces with a Schori pistol and form tough, highly resistant surfaces. Polythene cools to a hard film in a minute or two. Thiokol remains tacky for some hours after spraying but has remarkable impact resistance and therefore is used in shot blasting cabinets. Applications of polythene include coatings for metal stirrers and electrically insulating coatings for jigs and hangers in electroplating baths.—RPI.

Performance Tests for Protective Schemes Embracing Stoving Paints. Brit. Standard Inst., *Provisional B.S.,* 1391, 24 pp. (1947).

A specification for testing steel coated with one coat of paint applied over a pretreatment or metal coating. Details of the test and standards of assessment are given.—RPI.

Synthetic Coating. *Autom. Industries,* **97,** No. 12, 52 (1947) Dec. 15.

A synthetic coating, known as Unichrome coating, 218 of which can be built up to extra-heavy thicknesses was developed by United Chromium, Inc. Primarily designed to insulate and protect electroplating racks, it is a baking synthetic, applied by dipping or spraying and when cured at 350° F., becomes a sleek, elastic coating. It withstands mechanical abuse without chipping, tearing or lifting from equipment to which it is applied, and a variety of strong chemicals in addition to hot cleaning solutions and all plating solutions.—INCO.

Painting Aluminum Busses. *Auto. Industry,* **98,** No. 3, 40-41, 66, (1948) Feb. 1.

The Twin Coach Co., Detroit, Michigan, designed a number of aluminum masks to use when painting their buses which are 98 percent aluminum. These masks are clamped over the window moulding to protect both the window and moulding during painting. Lights and the decorative aluminum belt around the exterior of every coach also are masked. Masking paper or tape may be applied over the edges of the mask to completely seal the opening. After cleaning the entire surfaces, special areas are given a zinc chromate primer before the paint is sprayed on. Use of the masks enables as many as three colors to be sprayed at once. After the paint sets for a few minutes the masks are removed and the buses moved in to the baking ovens.—ALL.

Control of Wood Decay by Brushed-on Preservatives. New York State Forestry College, *Am. Paint and Oil Dealer,* **39,** No. 5, 18-9, 76-8 (1947).

A general review. Some comparative tests on various fungicides are reported. In these tests zinc or copper naphthenates were more effective than chlorinated phenols or PhHg oleate. More effective still were mixtures of the metallic naphthenates and chlorinated phenols—R.P.I.

Primers for Ferrous Metals in an Atmospheric Exposure. III. New England Paint and Varnish Prod. Club, *Am. Paint J.,* Convention Daily, **32,** No. 7-D, 23 (1947).

A progress report. A series of paints has been applied to cold-rolled Pang

In Bulletin 1, The Correlating Committee On Cathodic Protection Says—

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born, hot-holled angles, electrolytic zinc and ingot iron panels. Physical constants of the paints are reported, but no weathering tests are available.—RPI.

Use of Aluminum Paint Increased. American Metal Market, **55,** No. 14, 5, (1948) Jan. 21.

According to Aluminum Import Corporation, a member of the Aluminum Limited group, widened use of aluminum paint throughout the world is indicated by increasing sales of Alpaste. Large quantities of the material recently have been ordered from the company by paint manufacturers in various sections of Latin America, and by export houses for shipment to Europe, Africa and Asia. Because Alpaste is like liquid metal, it makes a durable, protective shield on wood, concrete, metal, brick and other materials. Because of the manner in which millions of minute aluminum flakes overlap each other, the paint has unusual opacity and coverage. It can be used both for finishing and as a primer.—ALL.

Asbestos Aluminum Coating. Alcoa Aluminum News Letter, Aluminum Company of America publication, page 4, (1948) Jan.

Alumi-Shield is a metallic coating combining tiny flakes of Alcoa Albron aluminum with weatherproofing material and asbestos fibres. This coating may be used on asphalt, concrete, metal or tar and is applied by brush or spray. On roofs it protects against the atmosphere and reduces summer temperatures. Its soft metallic sheen beautifies and modernizes concrete or cement structures. Alumi-Shield is manufactured by The Paraffine Companies, Inc., San Francisco, California, and Sommerville, New Jersey.—ALL.

Comparative Tolerance for Copper and Mercury of Some Organisms Promoting Fouling. C. M. Weiss, *Biol. Bull.*, **93,** No. 1, 56 (1947); *Chim. et Ind.*, **59,** No. 2, 164 (1948).

Resistance to anti-fouling toxins may be qualitatively estimated from the frequency of occurrence of the various species of marine organisms on fouled hulls. Among those commonly found, both Polysiphonia and Balanus amphitrite are resistant to copper and mercury. Watersipora cuculata is more resistant to copper than to mercury.—RPI.

Anti-Fouling Paint. A. Y. Thornell, *Paint Var. Prod. Man.*, **27,** No. 9, 255, 258 (1947).

A description of the special anti-fouling paint which allowed U. S. ships to remain long at sea in the Far East. The paint film can be applied directly without first removing the mill scale.—RPI.

New Synthetic Finish for Ferrous and Nonferrous Metals. Carl L. Shapiro, Acryrin Corp. of America, *Mat. & Meth.*, **27,** 62-64 (1948) Jan.

Tells how chemical pretreatments and primer coats can be eliminated in finishing metals by use of a new vinyl-type coating which dries in from 2 to 20 min. at 300° F.—BLR.

Clear Coatings with Rust Preventive Properties. Helen Sellei and Eugene Lieber, *Corr. and Mat. Prot.*, **5,** 10-12, 22 (1948) Jan.-Feb.

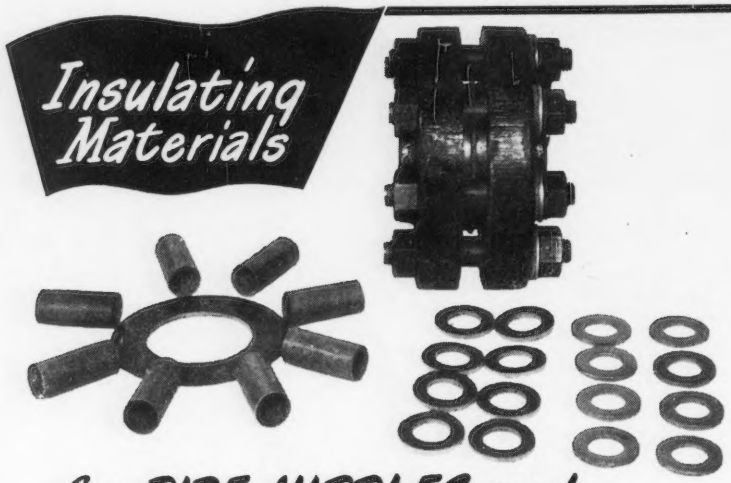
Reviews the background and initial development of transparent and readily removable coatings for use in packaging and storage of metallic parts and equipment. Includes photographs of test panels.—BLR.

New Experiments on the Corrosion Protection of Duralumin by Cladding. H. J. Seemann, *Metall* (Germany) Nos. 1 and 2, 8-15, (1947) Sept.

The corrosion resistance of aluminum-copper-manganese alloys is improved considerably by cladding with superpurity aluminum or aluminum alloys free from copper, especially aluminum-magnesium-silicon or aluminum-manganese alloys. Ingots are clad during casting or sheets of the core metals and cladding materials are rolled together. Important points in the fabrication and working of clad sheets are given and advice on the practical application of such metal is offered. Particular care must be taken that during heat treatment the copper does not break through the surface layer from the core metal, especially in the case of artificial ageing. (Neuhausen Wochenbericht [Switzerland] No. 31, 28th November—11th December, 1947.)—ALL.

Some of the Effects of Cadmium, Zinc and Tin Plating on Springs. J. R. Gustafson, Advance Print AP 5 from *Proc. ATSM,* **47,** 21 pp. (1947).

Fatigue and salt spray tests on plated high-carbon spring steels. Results are said to indicate the advantages of cadmium as a rust preventive, and it is stated that neither zinc or tin should be recommended for spring applications involving dynamic loading conditions.—BNF.



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Influence of Dissolved Tin on Growth of Clostridium Botulinum in Canned Vegetables. II — Experiments in Plain and Lacquered Cans. W. J. Scott and D. F. Stewart, *J. Council Sci. and Ind. Res.*, Australia, **18**, 173-80 (1945); *Paint Tech.*, **12**, No. 144, 475 (1947).

Canned vegetables were inoculated with Clostridium botulinum. Growth of the organism occurred consistently in lacquered cans, but in plain cans was inhibited for periods up to 6 months. Inhibition was due to the bacteriostatic action of dissolved tin. The minimum of tin necessary to prevent growth was directly related to the protein content of the vegetables.—RPI.

The Prevention of Rust. H. Sanders, *Mach. Lloyd* (Overseas Edition), **19**, 74-77 (1947) Dec. 6.

Discusses methods using greases, oils, solvents, plastics, etc., and their advantages and disadvantages for specific situations.—BLR.

Finishing Galvanized Iron Surfaces. Ivor Richards, *Organic Finishing*, **9**, 33, 36-40 (1948) Feb.

The problem of preparing the surface of galvanized-iron sheets for painting has not yet been completely solved; however, much progress has been achieved in recent years. This progress is reviewed.—BLR.

Mode of Action and Efficiency of Anti-Fouling Paints. H. Rabate, *Peint. Pig. Vernis*, **23**, No. 6, 165-7 (1947).

A review of the modes of action and types of anti-fouling paints. The adherence of fouling organisms is discussed. Above a speed of 15 knots, fouling does not take place.—RPI.

Marine Exposures of Cementiferous Painting Schemes. K. A. Pyefinch, *J. of the Iron and Steel Inst.*, **158**, 229-235 (1948) Feb.

Describes results of tests on painted steel specimens which were subjected to total and partial immersion in the sea for periods of up to 2 years. Three types of compositions were investigated. Types in which a cementiferous primer was covered by an oleoresinous antifouling coat gave excellent results; they were particularly promising for use at the water-line, where conventional combinations give unsatisfactory results.—BLR.

Zinc Chromate Protects Douglas "Skystreak." S. H. Phillips, *Paint Progress*, **7**, No. 1, 2 (1948).

Zinc chrome is of particular value for coatings for light metals. On aluminum its content of soluble chromate reduces the alkalinity of permeating water, which is the cause of the corrosion of aluminum, whereas it is a specific inhibitor for the corrosion of magnesium. Light metals are given the following cleansing treatment before painting; an alkaline cleansing bath; a hot water rinse, followed by a slightly acid rinse, and etching in hot chromic acid for a few minutes. A zinc chrome primer then is sprayed on. A U. S. Aeronautical performance specification (AN-TT-P-656b) for such a primer is quoted. The Douglas "Skystreak," an aluminum/magnesium alloy plane, is protected by a zinc chrome primer and finished with two coats of a N. C. lacquer.—RPI.

The Painting of Aluminum (F). J. J. Meynis de Paulin, *Rev. de l'Aluminum*, **24**, Nos. 137, 138, 309-317, 325-331 (1947) Oct., Nov.

Covers surface preparation (degreasing, mechanical roughening of surface, pickling, chemical oxidation, anodic oxidation) and the paints and lacquers used (properties of the various bases, passivating pigments, etc.).—BNF.

Corrosion Problems in Communication and Radio Equipment Design. L. P. Morris, *Corrosion*, **4**, 61-71 (1948) Feb.

A general discussion, including the action of fungi and methods for prevention by use of coatings.—BLR.

Report on Sodium Silicate Cleaners. A. B. Middleton, *Die Castings*, **6**, 65, 68-69 (1948) Jan.

Sodium silicates, when used to clean zinc and zinc-alloy materials prior to copper plating, often have been accused of leaving a film on the work which it is claimed, causes the subsequent copper plate to be non-adherent. Experimental work by Hazel and Stericker has shown that when the right type of silicate is used under properly controlled conditions, satisfactory results can be obtained. A review of the materials, conditions and procedures of the experimental work indicates that their conclusion is justified.—BLR.

Protective Finishes for Wood and Light Metal. Messerschmitt, *Off. Tech. Serv. Report PB. A 70795*, 12 pp. (1942); *N.P.V.L. Abs.*, No. 127, 286, (1947).

A report on the various kinds of protective finishes used for both wood and metal aircraft surfaces, how they are applied, what type to use and length of drying time.—RPI.

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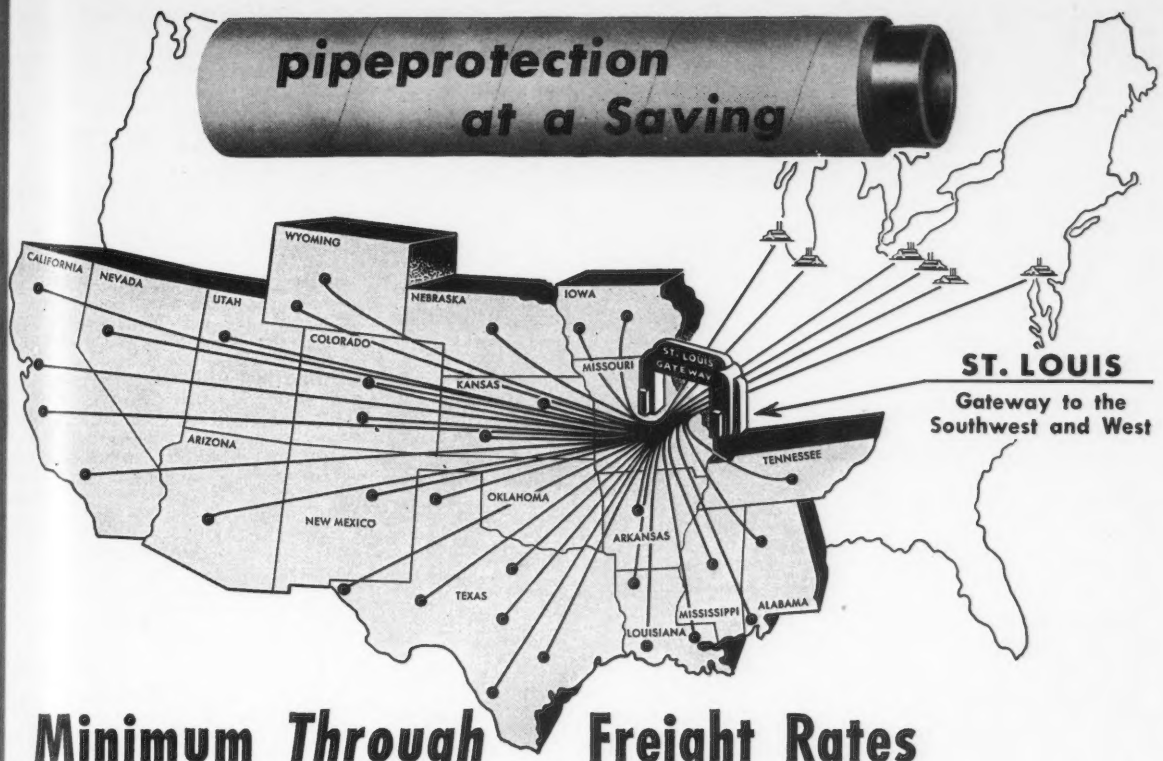

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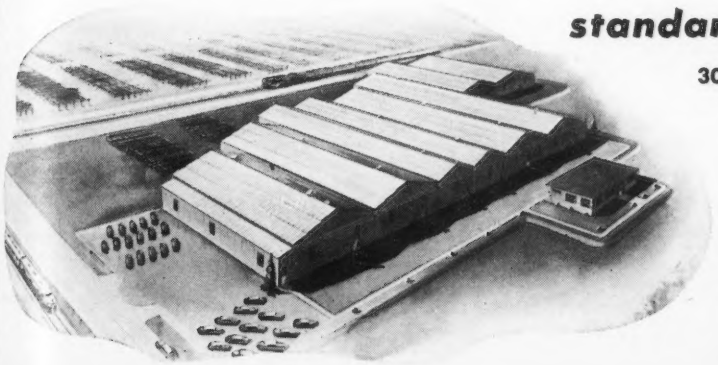

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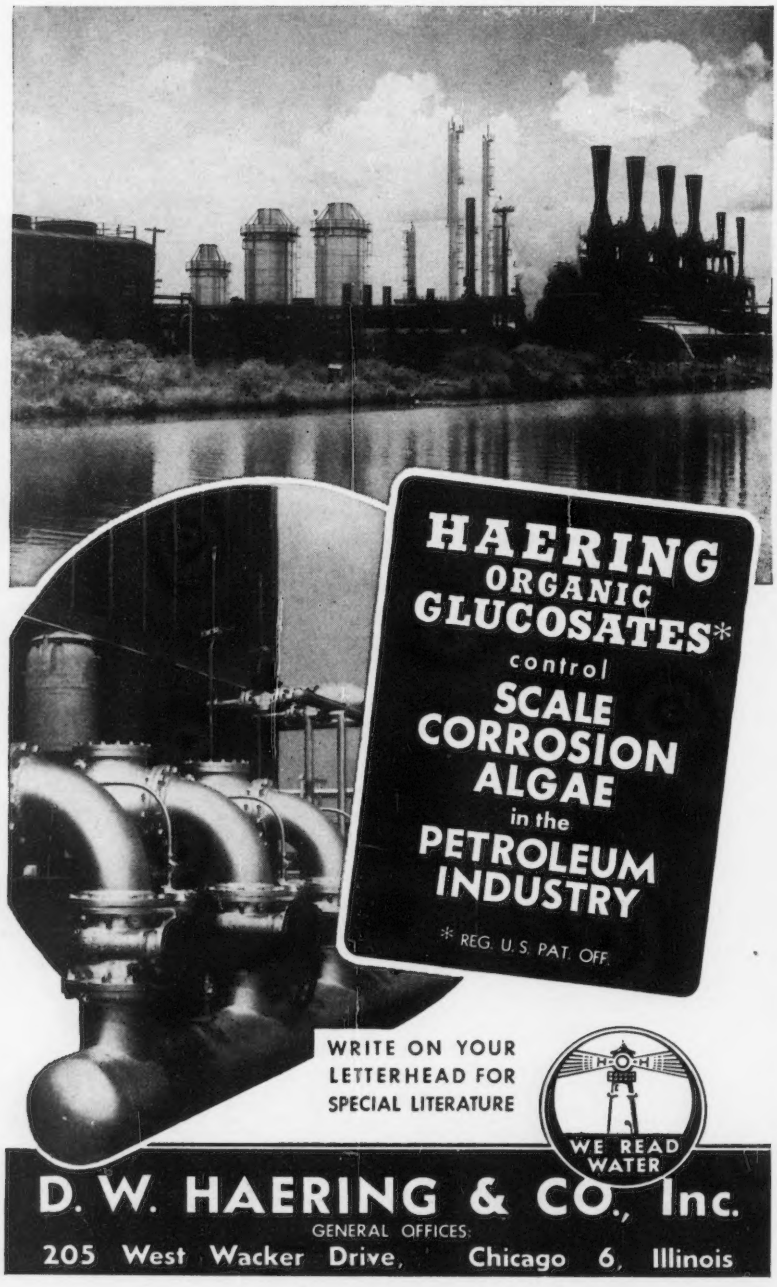
Anti-Fouling Coatings Tested by Scientists. R. J. McMahon, *Motorship*, **32**, 36 (1947); *J. Brit. Shipbuilding Res. Assoc.*, **2**, No. 12, 468 (1947).

Results of tests at Kure Beach and N. Florida are described. Copper flake paints were used and good results obtained.—RPI.

Cementiferous Paints. J. E. O. Mayne and R. S. Thornhill, *J. of the Iron and Steel Inst.*, **158**, 219-228, (1948) Feb.

Gives results of a study of the mechanism of setting and of the protection furnished to steel by cementiferous paints. These paints are based on mixtures of zinc dust and certain chloride solutions which produce a matrix of oxychloride cement by action on the zinc; sufficient metallic zinc is left to provide cathodic protection to steel exposed by pores. Of the chlorides tested, those of barium and strontium produce setting at high and low humidities; magnesium and calcium chlorides are satisfactory except at very high humidities. The oxychloride matrix is unstable in the presence of water, and cementiferous paints slowly disintegrate when immersed in sea-water. It is concluded that the best results will be obtained if the cementiferous paint is covered with an organic sealing coat. Twelve references.—BLR.

Chlorinated Rubber as Corrosion Resistant Coatings. J. B. Martin, *Organic Finishing*, **9**, 10-12+ (1948) Feb.



Describes performance and applications of the above for miscellaneous uses, including outsides of chemical tanks, reactors, etc.; sea-water immersion; car undercoatings; concrete paints and many others. Photographs of test panels show results of exposure for various times and conditions.—BLR.

Painting Exterior Steel Surfaces. R. Mansell, *Corrosion & Mat. Prot.*, **4**, No. 8-12 (1947).

A detailed review of surface preparation, paint application, and the formulation of paints for use on steel. The importance of proper surface preparation is emphasized and some methods are criticized unfavorably. Spray application is several times faster than hand brushing, but the latter has certain advantages and should be used if painting must be done in cold, damp weather. The properties of various rust-inhibiting pigments are described, with recommendations of suitable compositions for primers and top-coats. There are also notes on outdoor and laboratory exposure tests.—RPI.

The Metallizing Process. Part II—Applications. Rick Mansell, *Steel Processing*, **34**, 23-25, 44 (1948) Jan.

Describes use in Diesel-engine maintenance; in foundries; in babbitt work; in repair of cavitated areas, especially on the blades of hydroelectric turbines; for pump rods and plungers; and miscellaneous applications. Performance data and application methods are outlined for a few cases, giving suitabilities of different types of deposits.—BLR.

Assessment of Ships' Paints for Use in the Royal Navy. C. D. Lawrence & G. E. Gale, *Paint Tech.*, **12**, No. 138, 215-2 (1947); *J. of the Oil & Colour Chemists' Association*, **30**, 519-548; discussion, p. 549-556, (1947) Dec.

Methods of assessing paints are described. Final tests are carried out by sea-going trials. Laboratory methods used include the C. R. L. rotor tests for anti-corrosives, cracking tests for anti-fouling paints, and fire retardancy and condensation tests for interior paints.

Paint and the Winter. J. Lawrance, *Dec. Art*, **67**, No. 797, 26, (1947).

A discussion of the extra stresses in a paint system brought about by the extremes and violent changes in physical conditions caused by a hard winter and the probable resulting breakdown.—RPI.

Production and Use of Heat Resisting Aluminum Coatings. G. Kremer & K. E. Volk. Disc. by W. Mahling & Others, *VDE Comm. on Materials*, Report No. 65; *Stahl und Eisen*, **66-67**, 250-257 (1947).

A description of the different technical processes for the production of heat-enduring aluminum coatings is given. The appearance, microstructure (illustr.) and properties of the different aluminum coatings are dealt with. Carbon alloy steels included 18-8 and 18 chromium and cast steels can be protected by aluminum coatings. With cast iron, there are certain limitations. Resistance to scaling of the coatings depends on the processes used. Highest scaling resistance is shown by pack and hot dip calorized objects. Behavior of aluminum coatings in welding and practical applications are presented. Fourteen references.—INCO

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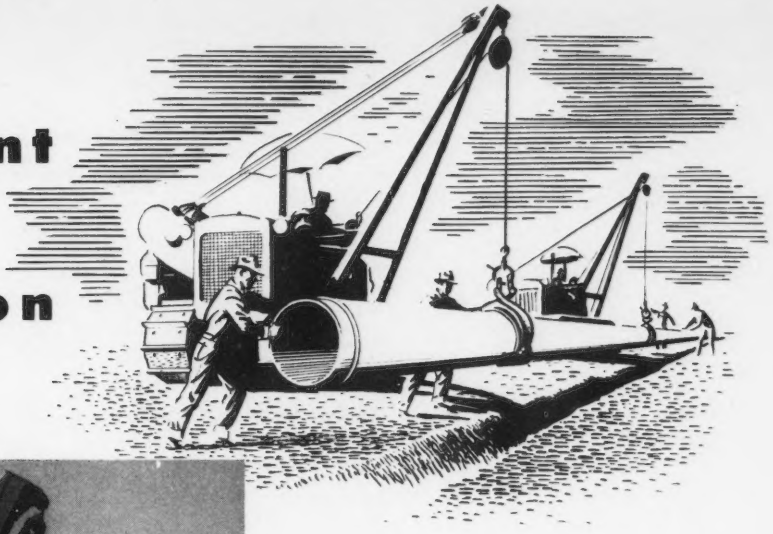

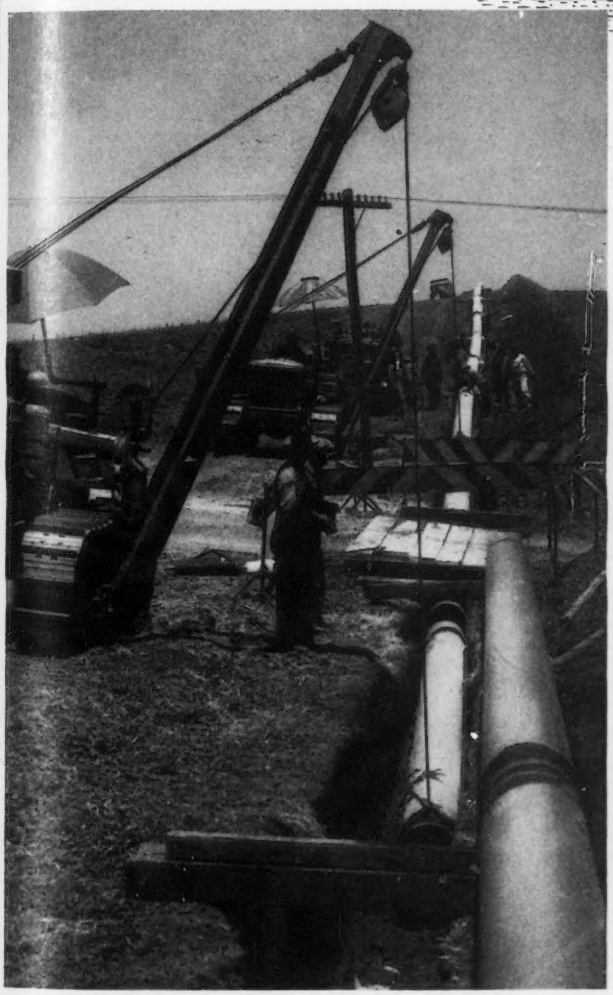

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Action of Antifouling Paints; Use of Glycerine Solutions as Accelerated Test of Availability of Toxic. Bostwick H. Ketchum, *Ind. and Eng. Chem.*, **40**, 249-253 (1948) Feb.

An antifouling paint which depends on copper or one of its compounds dissolves in an alkaline glycine solution about 100 times as fast as in the sea. The results of immersion for three days in the glycine solution predict whether the paint will maintain a copper-leaching rate adequate to prevent fouling. Satisfactory results were obtained with paints containing metallic copper or cuprous oxide.—BLR.

Chalking Behavior of Titanium Dioxide Pigments. A. E. Jacobsen, *Chem. Eng. News*, **25**, No. 40, 2895 (1947).

The chalking behavior of titanium dioxide pigments can be attributed to a cycline oxidation/reduction reaction involving the TiO_2 and vehicle. Reduced TiO_2 is reoxidized readily in presence of air and absence of actinic rays. A direct correlation has been found between photochemical reactivity and chalking behavior in alkyd-type TiO_2 paints.—RPI.

The Protection of Steel by Various Non-Metallic Coatings. J. C. Hudson and T. A. Banfield, *J. of the Iron and Steel Inst.*, **158**, 99-110, (1948) Jan.

This is an interim report on the behavior of a range of protective non-metallic coatings applied to structural mild steel and exposed to field corrosion tests of part of the investigations conducted by the Protective Coatings Sub-Committee of the British Iron and Steel Research Association. The tests cover periods of up to five years. Includes results of sea-water-immersion testing.—BLR.

Interior Coatings of Tubular Containers. L. P. Hubbuch and W. C. Johnson, *Ind. and Eng. Chem.*, **40**, 297-301, (1948) Feb.

The coating of the interiors of containers for certain poison gases was studied. Coatings based on straight 100 percent phenolformaldehyde resins were found resistant enough to prevent the decomposition of the gases which occurs when they are stored in contact with iron or steel. A modified dip method was worked out to provide uniform, thin, continuous coatings.—BLR.

How Ford Automobile Bodies are Phosphate-Coated. C. O. Herb, *Machinery*, **53**, No. 1, 150-4, (1946); *Paint Notes*, **2**, No. 7, 257-8 (1947).

After preliminary cleaning, the automobile bodies are sprayed all over with a cleaner consisting of 80 percent kerosene, emulsifying agent and soap at 160° F., and then washed with warm water at 160° F. The bodies then are sprayed with phosphate solution at 130° F., rinsed with cold water, sprayed with a chromic/phosphoric sealer and then heated to 320° F. by infra-red lamps to dry the bodies, after which the painting system is sprayed on to the body. Medium-size parts are phosphate coated by automatically dipping in phosphate solution at 210° F. Small parts such as nuts, bolts, etc., are carried through phosphate coating equipment while loaded in rotating wire-mesh barrels.—RPI.

Corrosion Protection of Japanese Ordnance. A. S. Henderson & Others, *B.I.O.S/JAP/PR/1463*, 11 pp. (1947).

Rifles, machine guns, etc., had an oxide coating 0.00001-0.00005" in thickness, which had little anti-corrosive value. Aircraft guns, etc., had an alkyd finish with good corrosion resistance. Three types of slushing oils were used.—RPI.

Chemical Finishing of Metals. F. P. Heard, *Monthly R.*, **34**, No. 9, 1035-1042 (1947).

Discussion of oxide and phosphate coatings on ferrous metals, black oxide coatings on copper alloys, and phosphate coatings on non-ferrous metals. Other processes for steel include heating to various temperatures and immersion in niter baths. Most troublesome alloying element is nickel. Such steels require a more concentrated phosphate solution and special care in preparation. The 30-point solution is used universally and will give good results with all except nickel steels, which require 45-50 points. —INCO.

Sulphur as a Protective Finish. H. W. Greenwood, *Paint Manufacture*, **18**, 50-51, (1948) Feb.

Tells how sulfur may be applied using the Schori flame-spraying pistol which was designed originally for metal-powder spraying only. States that properties of elementary sulfur render it worthy of consideration both for decorative and for protective purposes. It is completely water-proof, chemically resistant to many acids both inorganic and organic, is an excellent electrical insulator, a well-known fungicide, and has mild antiseptic properties.—BLR.

Corrosion Prevention by Sprayed Coatings. H. W. Greenwood, *Mech. World*, **122**, No. 3177, 596-8, (1947); *Rail. Eng. Abs.*, **3**, No. 2, 34, (1948).

A general review of corrosion and its prevention, with particular reference to the flame-spraying of powdered plastics or metals.—RPI.

Danger of "Masked Pores" and Methods for Their Determination. A. Glazunov, *J. Electrodepositors' Tech. Soc.*, **23**, 9-12, (1948).

"Masked Pores" in a metallic coating, e.g., an electro-deposit, are pores which have become covered over by some bridging mechanism. An electrographic porosity test shows up the actual pores very quickly, the "masked" pores after a little time. Author uses cellophane instead of filter paper for the test—BNF.

Low Temperature Phosphate Coating for Steel Easily Applied. Norman P. Gentieu, *Mat. & Meth.*, **27**, 74-75, (1948) Feb.

Describes reduction of the cost of rust-proofing steel by use of a process which can be operated at low bath temperatures. This is a cold-spray process known as Granodizing. Surface structures of treated and untreated sheet are illustrated.—BLR.

Protective Properties of Bituminous Paints. G. H. Fuidge, *Bull. Assoc. Mfr. Bituminous Products*, (1947) Nov.; *Decorator*, **46**, No. 548, 48, (1947).

The problems associated with the application of thick films of bituminous paints necessary for good resistance to corrosion are discussed.—RPI.

New Procedure for the Protection of Aluminum and its Alloys. M. J. Frasch, Paper presented to the Société de Métallurgie, (1947) Oct.

Metal is treated first with chromium phosphate and triethanolamine, then coated with bichromate-treated gelatin. This gives a highly resistant coating.—RPI.

Vehicle Paint Job Success Keyed to Surface Treatment. V. M. Darsey, *SAE J.* **55**, No. 9, 57-8, (1947); *Z.D.A. Abs.*, 5, No. 12, 178, (1947).

In the preparation of steel or zinc surfaces for painting, a phosphate treatment after cleaning is shown to be of value in inhibiting rust and improving adhesion. Photographs show treated and untreated parts after six years of outdoor exposure.—RPI.

Ceramic Coatings for High-Temperature Protection of Steel. Gilbert C. Close, *Steel Processing*, **33**, 751-754, (1947).

Presents results obtained by W. N. Harrison, D. G. Moore, and J. C. Richmond of the National Bureau of Standards, in cooperation with the NACA. They studied the use of a modified commercial enamel frit for the above purpose and obtained promising results.—BLR.

Low Temperature Phosphate Coating for Steel Easily Applied. N. P. Centieu, American Chem. Paint Co., *Mat. & Meth.*, **27**, No. 2, 74-75, (1948) Feb.

A new zinc phosphate material, Granodine, can be sprayed on at 120° F. alters both structure and nature of the metallic surface, and gives improved protection to steel sheets from rust and corrosion. Coatings can be varied from relatively thick, soft types to hard thin types. Process is called Granodizing.—INCO.

Physical Properties of Electrodeposited Metals: I. Nickel-1. Literature Survey. A. Brenner and C. W. Jennings, *Plating*, **35**, No. 1, 52-58, (1948) Jan.

This is the first publication of a research sponsored by the American Electroplaters' Society. The present literature survey covers composition and structure; mechanical and physical properties. A long select bibliography is provided. —BNF.

A New Method for Magnetic Measurement of the Thickness of Composite Copper and Nickel Coatings on Steel. A. Brenner & E. Kellogg, Nat'l Bur. of Standards, *Plating*, **35**, No. 3, 242-246, (1948) Mar.

By measuring the attractive force between the specimen and two permanent magnets of different strengths and the use of a set of calibration curves, total thickness of the deposit and the relative thickness of copper and nickel layers can be measured wih fair accuracy. Method is described.—INCO.

Chromated Protein Films for the Protection of Metals. A. Brenner, G. Diddell and R. Seegmiller, Nat. Bur. of Standards, Paper before Electrochem. Soc., Columbus, Ohio, April 14-17, 1948, *J. Electrochem. Soc.*, **93**, No. 3, 55-62, (1948) March.

Principal constituents of chromated protein films are a corrosion inhibitor for the metal, a protein which acts as a vehicle for this, a hardening agent and a bactericide to prevent putrefaction of protein. Either casein, albumin or gelatin is applied to metal surface by dipping, and film impregnated with chromate. The effective life of coatings depends on

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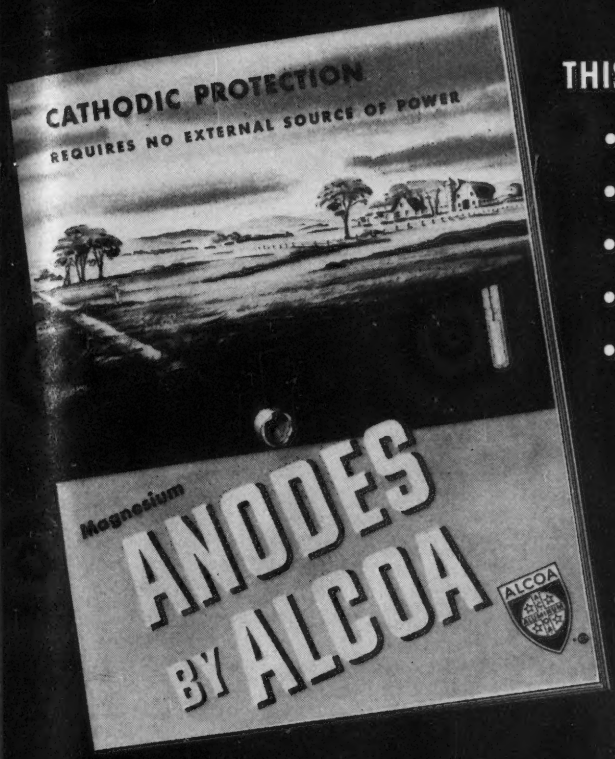

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length of time chormate is retained. In outdoor exposures, film loses its value quickly. In sheltered environment, such as storage, films are useful. Sheet steel which ordinarily rusts within a few days in a chemical laboratory remains bright several months with the chromated protein coating. Results of salt spray, indoor and outdoor exposure tests comparing these coatings with other supplementary films such as inhibited oil, phosphate, chromate and anodized films are reported with data. Films protect zinc, steel, aluminum and brass but have little or no protective value for magnesium or copper.—INCO.

Is it Possible to Calculate the Life of a Paint by the Examination of Thin Films? J. F. Bogstra, Paper presented to the Société de Métallurgie, October, (1947).

A mathematical expression has been derived from experimental results purporting to give a relationship between thickness and life of paint. There is, as yet, however, little experience in support of the expression.—RPI.

Comparative Tests on White Lead and Zinc Oxide Paints. A. V. Blom, *Verfkroniek*, **20**, No. 8, 143-5, (1947).

Three typical white lead paints and three typical zinc-oxide paints on iron and wood panels have been subjected to natural exposure, 45° south, at Zurich (493 m.) and Clavadel (1700 m.). A red lead primer was used for the lead but not for the zinc paints on the iron. After three years the lead paints were in all cases superior. On accelerated weathering the difference was even more marked; the iron panels coated with zinc paints rusted through in 3 weeks, whereas the lead paint coated panels were still good after 4 months.—RPI.

Plating Zinc Die-Castings; Pre-Treatment Prior to Bright Nickel Deposition. P. Berger, *Met. Ind.*, **72**, 88-90, (1948) Jan. 30.

Methods for preliminary treatment, an operational sequence suitable for rapid production plating, and methods for the prevention of undesirable phenomena, such as over-cleaning, are discussed. Reference is made also to the interactivity of zinc as a base metal for electrodeposited under-coatings such as copper and brass. (To be concluded.)—BLR.

Copper in Diatoms. N. I. Hendey, *Nature*, **159**, No. 4045, 646, (1947); cf. H. Barnes & K. A. Pyefinch.

Marine diatoms removed from the slime film formed on a raft in the sea contained 31-164 p.p.m. copper. It is suggested that they may have an anti-fouling action.—RPI.

Copper in Diatoms. H. Barnes & K. A. Pyefinch, *Nature*, **160**, No. 4055, 97, (1947).

Polemical against Hendley above. Anti-fouling action is due to release of copper and there is no evidence that slimes associated with diatoms act as anti-fouling surfaces.—RPI.

Causes of Failure of Plated Coatings in Automotive Service. E. A. Anderson and C. E. Reinhard, *Plating*, **35**, 145-152, (1948) Feb.

Presents results of a thorough investigation of 71 plated, zinc-alloy, die-cast parts, mostly from 1941-model cars with five years service, from different locations, in order to permit comparisons among different atmospheric environments. The data are tabulated, illustrated, and discussed.—BLR.

Anti-Fouling Paints. Inactivation of Highly Pigmented Anti-Fouling Paints Applied to Steel. A. L. Alexander & R. L. Benemelis, *Ind. Eng. Chem.*, **39**, No. 8, 1028-32, (1947).

Metallic copper has been found less satisfactory than cuprous oxide for anti-fouling paints on steel because it becomes inactivated. This is due to the formation of a galvanic cell, leading to corrosion of steel. At pigment concentrations above a certain limit, the film becomes conducting and the couple operates. Conductivity is not due to contact of particles with one another and with steel, because films are not always conducting when dry, but only after soaking for some time. It is suggested that either particles change position on soaking or copper dissolves and is then deposited on the steel from solution.—RPI.

Antifouling Paints. A. L. Alexander, P. King, and J. E. Cowling, Naval Res. Lab., *Ind. and Eng'g Chem.*, **40**, No. 3, 461-464, (1948) Mar.

Describes in detail the experimental work that led to formulation of efficient antifouling films no more than two mils in thickness, which effectively prevent attachment of marine organisms to submerged surfaces for periods up to eight months. Data are presented as to method of evaluating such finishes along with comparative fouling data from several locations. Certain resinous constituents commonly considered as possessing poor wetting or grinding properties are demonstrated to be more efficient in carrying toxic pigment for antifouling purposes than are the better grinding media. Hulls of flying boats are application especially in mind. Tables give fouling ratings, etc.—INCO.

1947 Progress in Metal Finishing. W. A. Raymond, *Metal Finishing*, **46**, No. 1, 56-60, (1948) Jan.

Increased investigation and research into the theoretical and academic aspects of electrochemical processes for metal finishing was noticeable during 1947. Particularly noticeable was the decided increase in the number of papers on the theoretical phases of metal finishing that were given at the American Electroplaters Society National Convention and the Third International Conference on Electrodeposition. Conventional methods of wheel polishing were improved by increased use of automatic equipment. Patents were issued for several new types of abrasive wheels. Increased use of non-glue binders, with evidence of superiority for certain classes of work, was reported. The use of belt methods increased. Electrolytic methods of surface preparation were the subject of widespread interest and development. A new method of abrasive blasting was developed which utilizes the propelling power of a burning gas to drive the abrasive particles. Much attention has been paid to improvement of cleaners and detergents, with the development and use of wetting agents playing a large part in the stepped up efficiency and speed of modern prepared cleaners. Plating on magnesium with zinc, nickel-tin, and silver and lead alloys was developed, and a patent was issued for depositing copper, zinc, cadmium, tin, silver, and gold on magnesium surfaces. Chemical surface treatments other than electroplating also saw considerable activity in the past year. A patent was granted for galvanizing or tinning aluminum from molten baths. A preliminary zinc immersion deposit from zincate solution, commonly used for electroplating pretreatment was an essential step in the process. A new technique and equipment for "spot" or restricted area plating was developed using solution velocities as high as 100 feet per second to promote rapid deposition of metals at very high current densities. The application of reverse current methods of electroplating created considerable interest and further industrial use of the technique should develop rapidly.—ALL.

CHEMICAL CORROSION

Action of Acid and Alkaline Solutions on Ceramic Bodies. R. Ricke, *Ber. deut. Keram. Ges.*, **21**, 477-487 (1940); *Brit. Abstracts*, BI, 258, (1947) Sept.

Methods for testing the chemical resistance by measuring weight loss sustained by powdered materials are discussed in detail and data for the resistance of stone-ware, an acid-resisting brick and porcelain and steatite bodies to concentrated sulfuric acid plus nitric acid heated to fuming point and concentrated sulfuric acid (refluxed) are recorded and discussed.—INCO.

Effect of DDT Smoke Bomb on the Materials of Aircraft Construction. W. R. Day, *Off. Tech. Serv. Report PB. A 47867*, 14 pp. (1945); *N.P.V.L. Abs.*, No. 126, 26 (1947).

Two tests were carried out with DDT smoke bombs in order to determine the damage to aircraft materials. Composition of the bomb was sodium chlorate, 14 percent; sucrose, 36 percent; DDT (commercial), 52 percent. A description of the tests is contained in Appendix 1. Result of the tests are contained in Tables 1-4, Appendix 2. The extent of corrosion of the metals is shown in photographs, Figures 1-6, Appendix 2. Products of the DDT smoke bombs were seriously corrosive to the metals used in aircraft construction (Alclad 24 S-T, Aluminum 24 S-T, copper, magnesium, stainless steel 18-8). All other materials tested such as plastics, camouflage enamel, gloss lacquers, sealing compounds and rubbers, were relatively unaffected by the bomb fumes with the exception of zinc chrome primer, which was softened by the heavy concentration of smoke.—RPI.

Comparison of Pickling Acids. Anon. *Wire Ind.*, **14**, No. 166, 558 (1947); *Z.D.A. Abs.*, **5**, No. 12, 178 (1947).

A comparison of sulfuric and hydrochloric acids for wire pickling. In Europe and the U. S. A. sulfuric acid is used almost exclusively, but it requires closer control of concentration and temperature and of iron content, if it is to work with optimum efficiency. Main advantage of hydrochloric acid is that it can be used at room temperature. Silica grains are sometimes found on wire surfaces and may be dissolved by 10 percent hydrofluoric acid.—RPI.

Scale Removal. Birmingham Metallurgical Soc., *J. Birmingham Met. Soc.*, **27**, No. 3, 354-77 (1947); *Z.D.A. Abs.*, **5**, No. 12, 179 (1947).

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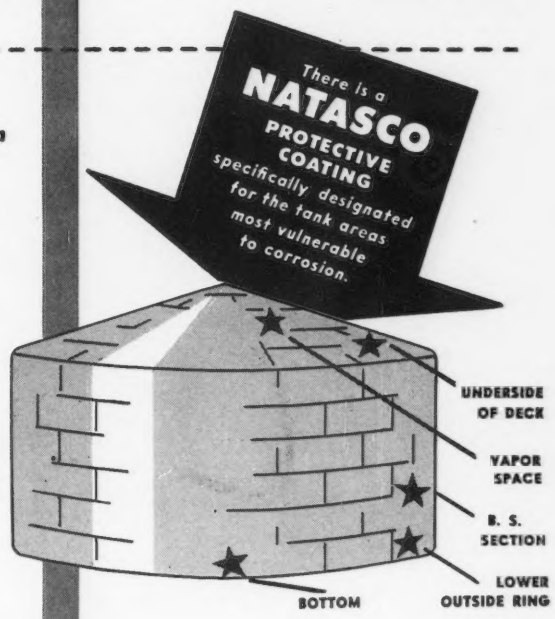

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Subjects raised included the formation and types of scales occurring on various ferrous and non-ferrous metals and alloys; chemical and electrolytic pickling; sand and shot blasting; the disposal of waste liquors. A detailed account is given of sodium hydride descaling, which has been used commercially in the U. S. A. for about two years.—RPI.

Concentrated Rust Solvent. *Corr. & Mat. Prot.*, **5**, No. 1, 25 (1948) Jan.-Feb.

"Consa-rusto" is a solvent compounded from a complicated formula of inhibited acids combined with a wetting agent, containing no hydrochloric acid, nitric acid or sulfuric acid. It will not attack bare ferrous metals, since it dissolves rust oxides only, although it will mildly attack aluminum and zinc. Is effective in cleaning pipe lines buried near the sea, removing rust from oil tanks and refining equipment, and cleaning castings before they are coated. Announced by Consolidated Sales Agency, Dallas, Texas.—INCO.

What to Look for in Hydraulic Oils—VII. Non-Corrosive Qualities. (Concluded). Anthony J. Zino, Jr., *American Machinist*, **92**, 126-128 (1948) Feb. 12.

Discusses tests for determining above properties.—BLR.

The Treatment of Plating and Pickling Shop Wastes. E. W. Mulcahy, *J. of the Electrodepositors' Tech. Soc.*, **22**, 227-242 (1947) (Reprint).

Deals with methods of neutralizing acid from waste liquors and rinse water; the precipitation of chromium, copper, iron, etc.; the removal of cyanide in effluents; the construction of effluent treatment tanks of suitable acid-proof materials; the measurement of flow and pH recording apparatus; the removal and scrubbing of nitrous oxide fumes from bright dipping plants; figures for intake air velocity on extractors; hard rubber as protective lining for tanks and fan casings; study of the recovery of waste pickle liquors from industrial pickling plants; and a description of a plant for the crystalization of ferrous sulfate. —BLR.

Anodic Reactions of Aluminum and its Alloys in Sulphuric and Oxalic Acid Electrolytes. R. B. Mason and C. J. Slunder, *Ind. and Eng. Chem.*, **39**, No. 12, 1602-1607 (1947) Dec.

This article describes factors such as temperature, concentration and agitation of electrolyte, time of treatment, current density, and type of alloy treated, which affect the formation of aluminum oxide produced by the anodic treatment of aluminum in sulphuric and oxalic acid electrolytes. Electrolytes used at elevated temperatures or in a more concentrated form tend to produce oxide coatings of lighter weight. The electrolyte must be sufficiently agitated to remove the heat developed at the aluminum anode; otherwise, the oxide coating is dissolved. Long time treatment in the electrolyte brings about a decrease in the efficiency of oxide coating formation. Likewise a decrease in the current density results in the formation of a lighter weight oxide coating. Purity of the aluminum anode has a marked effect upon the efficiency of oxide coating formation, the highest efficiency being obtained with pure aluminum.—ALL.

The Corrosion of Silver in a Water-Saturated Chlorine Atmosphere. H. B. Linford and M. J. Ford, *J. Electrochem. Soc.*, **93**, No. 1, 16-26 (1948) Jan.

The corrosion of pure silver (99.97 percent) in a saturated chlorine atmosphere was studied. The corrosion rate initially indicated that above 44° C. a negative temperature coefficient was obtained. After an extended period of time the temperature coefficient was positive up to about 90° C. The effects are explained on the basis of concentration of active agent and its diffusion through the film of silver chloride.—BNF.

Bleaching Groundwood-Sulphite Pulp. J. A. Lee, *Chem. Eng.*, **54**, No. 10, 92-96 (1947) Oct.

Use of sodium peroxide as a bleaching and pulping agent in the St. Regis Paper Co. mill is described in detail. Various parts are of stainless steel, such as dissolving tank and agitator, lines for transferring bleaching solution, Type 316 stainless pipes throughout bleaching plant (to prevent specks in final paper which generally result when iron pipe is used). Acid, silicate and sulfur dioxide storage tanks are of mild steel. La Bour pumps handle acid.—INCO.

Corrosion of Filters in Sugar Refineries. Part IV—Investigations on Flowing Liquors. H. Inglesent, E. M. Manackerman, and J. Anderson Storrow, *Ind. Chem. and Chemical Manufacturer*, **24**, 76-84 (1948) Feb.

Measurements were made of the differences between electrode potentials of common constructional metals in flowing sugar liquors at temperatures up to that in operating plant. Results are charted and discussed.—BLR.

The Effect of Nicotinic Acid (β-Pyridine Carbonic Acid) in Reducing the Solubility of Metals. L. Hertelendi, *Archiv fur Metallkunde* (Switzerland) **1**, No. 6, 275-278 (1947) June; *Neuhausen Wochenbericht*, (Switzerland) **2**, No. 30, (1947) Nov. 19-27.

In experiments on test sheets of high purity aluminum, aluminum-magnesium alloy, zinc and steel, it was determined that the attack of mineral acids such as nitric acid, sulphuric acid and hydrochloric acid in varying concentrations was more or less retarded by additions of nicotinic acid. In order to be effective, the nicotinic acid concentration must be at least 1 percent in the case of the action of of nitric acid on aluminum. The protective effect of 2 percent nicotinic acid proved somewhat stronger against the attack of hydrochloric acid but in the case of sulphuric acid, was practically negligible. The nicotinic acid forms an adhesive, adsorptive layer. A certain percentage of the attacking acid must be replaced by nicotinic acid.—ALL.

Corrosion Tests in Sulfuric Acid in Petroleum Refinery Processes. W. Z. Friend, International Nickel Co., *Corrosion*, **4**, No. 3, 101-111 (1948) Mar.

Presents results of a number of plant corrosion tests and of several laboratory tests using spool-type specimen holder. Compositions of the metals and alloys used for test include Monels, Hastelloys, Durimets, stainless steels, alloy steels, 70/30 copper-nickel, chemical lead, Worthite, copper, bronzes, Ni-Resist Type I. Acid treatment of lubricating oils and other distillates require different materials depending on temperatures, concentrations and aeration. In the production of alcohols from refinery gases, acid concentrations of 65-95% sulfuric acid are used. The alcohols are stripped from the acid solutions with live steam. Monel is used for absorption and cooling equipment where acid concentrations of 65% or lower are met under conditions of low velocity. Hot acid polymerization processes employing 63-72% H_2SO_4 at 165-200° F. and H_2SO_4 alkylation processes employing 95-100% H_2SO_4 at 30-50° F. are discussed, also the recovery of used acid by evaporation.

Commercial Scale Manufacture of Allyl Chloride and Allyl Alcohol from Propylene. A. W. Fairbairn, H. A. Cheney, and A. J. Cherniavsky, *Chem. Eng. Prog.*, **43**, 280- 290 (1947) June; *Corr. and Mat. Prot.*, **4**, No. 5, 20 (1947) Sept.-Oct.

Includes brief attention to materials of construction and corrosion problems. —INCO.

The Sodium Hydride Process and New Method of Descaling Metals; Application to Wire and Strip. N. L. Evans, *Wire Industry*, **15**, 105-107 (1948) Feb.

Describes the process and equipment necessary, the method of constructing it, and the manner of its operation for wire and metals in other forms.—BLR.

Salt Descaling Baths. Horace Drever, *Ind. Heating*, **15**, 40, 42+ (1948) Jan.

Two types of the above which serve to illustrate the significant differences between all processes which are most frequently encountered, are described. These are the sodium hydride and the sodium hydroxide processes. The methods are useful for both ferrous and nonferrous metals.—BLR.

Cast-Iron Crucibles; Corrosion by Molten Aluminum. Marcel Bardot, *Iron and Steel*, **21**, 23-26 (1948)Jan. Ibid. 49-51 (1948) Feb. Translated from *Fonderie*, 798-810 (1947) Sept.

A summary of a bibliographic study preparatory to further research. Eighteen references.

Corrosion of Lead by Sulfur Dioxide. (In French.) Andre Chretien and Jean Broglin, *Comptes Rendus* (France), **225**, 1315-1317 (1947) Dec. 22.

Using same apparatus as previously described for study of corrosion of other metals by various gases, the effect of SO_2 on lead was investigated. During the reaction, the temperature dropped from 725° to 690° and the pressure rose from 137 to 760 mm. mercury. Two phenomena occur successively: the gas is fixed by formation of the dibasic sulfide and sulfate, then it is liberated by reversal of the reaction.—BLR.

Scale Removal. E. Bucknall, *J. of the Birmingham Metall. Soc.*, **27**, 355-363; discussion, 354-355, 363-377 (1947) Sept.

A general discussion of the above subject, applicable to both ferrous and nonferrous metals and alloys. Fifteen ref.—BLR.

Passivation of Stainless Steel. F. H. Beck, *Engineering Experiment Station News*, Ohio State University, **19**, 32-3[illegible] (1947) Dec.

Results of experimental work outlined indicate that the passive film is a layer of physically adsorbed gas on the metal surface or possibly a physically ad-

sorbed gas layer on a hydrous oxide film formed by the passivating methods. Describes method used for passivating stainless steel and for corrosion testing; as well as the vacuum breakdown apparatus. Also outlines use of synthetic sea water, repassivation by inert gases and electron-diffraction work.—BLR.

Aluminum Containers for Sodium Chloride. J. P. Balash, *Chem. Eng.* **55,** No. 1, 224, 226, 228 (1948) Jan.

Sodium chloride in both solid form and as brines has been handled satisfactorily in aluminum equipment. In the presence of contaminants such as compounds of copper, nickel and lead attack will be very small and highly localized. Use of Alclad material in this case will greatly minimize danger of corrosion. Equipment to handle sodium chloride should be designed to avoid contact of dissimilar metals. Aluminum alloys are unaffected by unpolluted sea water but for water polluted by industrial wastes, Alclad metals are recommended because they are resistant to localized failure. Brines have been used successfully in refrigeration systems made of aluminum alloys. Oil well brines are being handled in aluminum piping. Condenser tubes are being fabricated of Alclad 3S which is particularly desirable where the corrosive waters contact the inside of the tube. Preliminary processing equipment for refining salt is all composed of aluminum. Wooden containers for salt are lined with aluminum sheet to prevent moisture seeping in and salt leaking out. —ALL.

Aluminum Containers for Nitric Acid, J. P. Balash and E. D. Verink, Jr., *Chem. Eng.,* 55, No. 2, 236, 238 (1948) Feb.

Most of the large producers of nitric acid, made by the ammonia oxidation process, have used aluminum for many years. Concentrated nitric acid (80 percent or above) and its vapors have only slight effect on it at room temperature. Aluminum is used commercially in reaction vessels for the catalytic oxidation of ammonia and cooling coils or condensers, for the concentration of the acid, as well as pressure piping. To handle concentrated nitric acid (80 percent or greater) made by the ammonia oxidation process, aluminum alloy storage tanks, I.C.C.-approved tank cars, siphons, and containers are employed. Nitrous gases as a rule can be handled in aluminum, although the lower oxides, when dissolved in nitric acid may increase the rate of attack slightly. Aluminum hoods, ducts, and covers for nitrating tanks are widely used for the handling of gases which contain oxides of nitrogen. In the manufacture of nitric acid base explosives, the non-sparking property of aluminum, as well as corrosion resistance is used to advantage. Aluminum evaporators and crystallizers have been used for the processing of ammonium nitrate, thereby avoiding harmful contamination.—ALL.

CONSTRUCTION MATERIAL

Processing Vegetable Oils. *Chem. Eng.,* 54, No. 8, 109 (1947) Aug.

In a plant which produces a variety of fatty acids, drying oils and other organics, materials of construction include Monel, stainless, Inconel and aluminum. Color-free products must be produced. Illustrations from the Woburn, Chem. Corp., Kearny, N. J., show Monel Twitchell tanks where glycerine is made from fatty acids, special alloy condensers and receivers and other parts of the plant.—INCO.

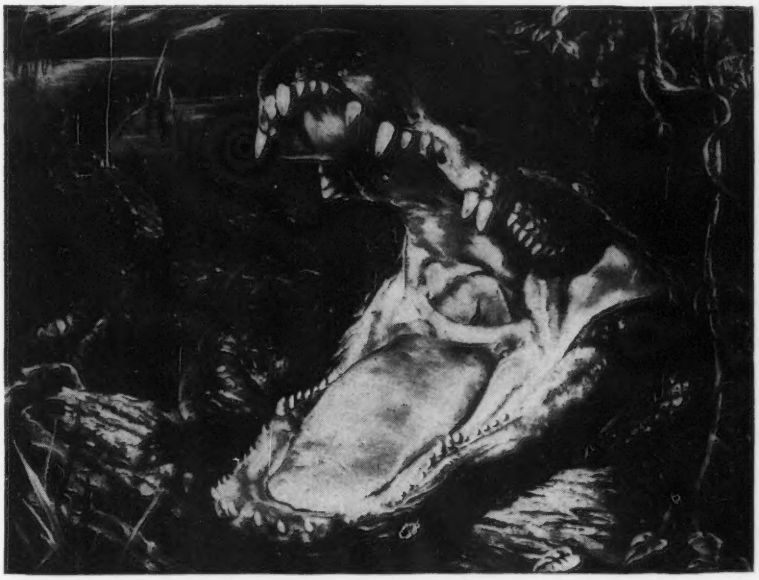
Fabricating and Finishing Stainless Steel. Parts I and II. A. P. Schulze, *Metal Fin.,* **46,** No. 1, 72-77 (1948) Jan.; Ibid. No. 2, 59-64 (1948) Feb.

Part I deals with complete cleaning techniques other than pickling, including removal of drawing lubricants prior to annealing, emulsion pre-treatment, alkaline still-tank cleaning, electrolytic cleaning and other cleaning methods. Various references to trade literature. Part II gives further information on surface treatments for stainless steel, covering scale removal by sand-blasting, pickling, molten and aqueous alkali solutions, and passivating. Formulas and methods used in the most modern processes are described. Ten ref.

FUNDAMENTALS

Intercrystalline Corrosion of Super-Pure Aluminum and its Bearing on the Nature of the Grain Boundary. P. Lacombe and N. Yannaquis, *Metaux & Corrosion,* **22,** No. 259, 35-37 (1947) March; *Compt. rend.,* **224,** 921-922 (1947).

Study of corrosion of 99.9986% aluminum in hydrochloric acid solution with and without an applied potential. It was observed that boundaries between grains of dissimilar orientation were heavily attacked, but not those between grains of similar orientation. Doubt is thus cast on impurity segregation as the



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cause of intercrystalline corrosion.—BNF.

Corrosion Characteristics of Some Magnesium - Zinc - Calcium Alloys. G. C. Kucznyski and F. Schonfeld, *J. of the Electrochem. Soc.*, **93,** No. 2, 41-46 (1948) Feb.

The resistance to corrosion of 45 cast magnesium-zinc and magnesium-zinc-calcium alloys containing up to 5.5% zinc and 0.7% calcium was investigated by fourteen day exposure to an alternate immersion test in 3% sodium chloride solution. While zinc greatly improves the mechanical properties of magnesium, the corrosion rate increases with increasing zinc content. Some alloys containing more than 6% zinc were practically disintegrated after an exposure of two weeks. However, the addition of calcium to magnsium-zinc alloys offsets almost completely the deleterious effect of zinc. The corrosion rate is reduced rapidly as the calcium content is increased from zero to about 0.1%, is approximately constant for a given magnesium to zinc ratio up to about 0.5% calcium, then increases as the calcium content is increased. In the case of 5.5% zinc in magnesium, the addition of calcium lowers the corrosion rate by more than 60%. As such alloys are solid solutions, the possibility of galvanic corrosion may be ignored and the following mechanism tentatively explains the results of the experiment. While the formation of magnesium hydroxide on pure magnesium slows down the corrosion rate, the addition of zinc precipitates the hydroxyl ions from the solution in the form of zinc hydroxide, owing to its lower solubility product constant, and the magnesium continues to dissolve. If calcium is added in suitable concentration it will go into solution producing additional hydroxyl ions and because the calcium hydroxide solubility product constant is much higher than that of magnesium hydroxide, it will lower appreciably solubility of the latter by the common ion effect, forcing magnesium hydroxide out of solution and causing it to be deposited on the surface of the alloy. Some zinc hydroxide is deposited also and in the case of a calcium concentration higher than 0.5% some precipitate of $Mg_5Ca_2Zn_6$ occurs, causing galvanic corrosion.—ALL.

Oxide Films Formed on Titanium, Zirconium, and Their Alloys with Nickel, Copper and Cobalt: An Electron Diffraction Study. J. W. Hickman and E. A. Gulbransen, *Analytical Chemistry,* **20,** No. 2, 158-165 (1948) Feb.

The electron diffraction technique is used to study the structures of the oxides which form in the temperature range 300°-700° C. on titanium and zirconium and on the alloys titanium-nickel 50/50, titanium-nickel 70/30, copper-titanium 28/72, copper-zirconium 80/20, zirconium-cobalt 60/40, and zirconium-nickel 70/30. Attempts are made to correlate the structures obtained with thermodynamic data reported by other workers.—BNF.

Some Observations on the Influence of Cold Work on the Solution Potential of Aluminum. Y. Druet and P. A. Jacquet, *Metaux et Corrosion* (France) **22,** No. 265, 139 (1947) Sept.

The authors have repeated some of the work of P. Morize using a slightly different technique. The solution potention was determined by measurement with a potentiometer BEMF of the cell made up with a sample immersed in a 3% solution of sodium chloride and a reference electrode. Curves relating to potential and time were obtained. The time extended up to five minutes. Superpurity metal of 99.998% purity was used. The samples were taken from heavily cold worked aluminum and from the same metal following an annealing for one hour at 480° C. In the case of the cold worked sample, best reproducibility was found to be obtained when the measurements were made one hour after rolling. The mechanically polished sample gave a value of —.75 volts. The electrolytically polished samples gave the following values: Annealing condition —1.384 volts, cold worked condition —1.428 volts. The X-ray diffraction patterns revealed a certain amount of recrystallization in the cold worked samples. The authors suggest that the heat of an electrolytic polish was sufficient to result in some recrystallization. They point out that some points of technique may be open to question and mention that they plan to improve their technique and obtain additional information. —ALL.

The Amorphous and Crystalline Oxide Layers of Aluminum. A. J. Dekker and W. C. van Geel, *Philips Research Reports* **2,** 313-320 (1947). *Chem. Absts.* **42,** No. 2, 438-439 (1948) Jan. 20.

By anodic oxidation, aluminum can be covered with either an amorphous or a crystalline oxide layer. The amorphous layer, which is porous, is obtained in solutions of oxalic, sulfuric or phosphoric acids. Porosity is proportional to the current density. The crystalline layer is obtained in aqueous solutions of a borate, succinate, of citrate, and has pronounced insulating properties. When a crystalline layer is formed on a surface that has been coated with an amorphous layer, the crystalline layer is formed in the pores of the amorphous layer until these are filled. The capacity of an aluminum surface covered with a crystalline layer is the same as that of a surface that has been covered first with an amorphous layer and then a crystalline layer; this indicates that the dielectric constants of amorphous and crystalline Al_2O_3 must be equal.—ALL.

GENERAL CORROSION

I. Three of the Eight Forms of Corrosion. II. Galvanic Corrosion and Concentration, Cell Corrosion, Mars G. Fontana, Ohio State Univ., *Metal Prog.*, **53,** 231-233, (1948) Feb.; Ibid **53,** 382-386 (1948) Mar. Portion of Mss. for "Book of Stainless Steels," 3rd ed.

First portion discusses uniform attack, intergranular corrosion and pitting. Not confined to ferrous metals. Illustrated. Second portion discusses two common forms of corrosion and palliatives are briefly noted. Recognition of galvanic corrosion, cathodic protection and sacrifial anodes and impressed current are discussed. To avoid concentration cell corrosion, whose mechanism is explained, butt welded joints with complete weld penetration are recommended. (If lap joints cannot be avoided joints should be cleaned and sealed by welding or caulking.) Existing joints should be cleaned and sealed. Sharp corners and stagnant areas that would favor accumulation of deposits should be avoided and all equipment should be cleaned periodically.

Symposium on Corrosion and Metallurgy. *Revue de l'Aluminium* (France), **24,** No. 138, 345-348 (1947) Nov.

La Société Française de Métallurgie held a joint conference in Paris with La Commission Technique des Etats de Surface des Metaux, from October 6th to 10th, 1947. About 100 papers were presented by delegates from nine countries. The sessions were divided into two parts: I. CORROSION. At the opening meeting U. R. Evans presented a paper on "Theoretical Aspects of Corrosion and Oxidation." The following subjects were dealt with at subsequent sessions: (a) Surface Condition and Protection by Painting, which included papers by P. Peissi on aluminum-tar paint, N. Beliaeff on corrosion testing of various alloys protected by anodic oxidation and anti-fouling paint, and E. Morlet and F. Danis on the effect of electrolytic polishing on corrosion; (b) Theories of Corrosion, to which G. Chaudron and C. Benedicks contributed important papers; (c) Cathodic Protection, especially pipeline protection, which was discussed by R. de Brouwer, F. N. Speller and J. E. Raclot; (d) Dry Oxidation and Intercrystalline Corrosion, which included the paper by P. Lacombe and N. Yannaquis on the influence of crystallographic factors in high-purity aluminum; (e) Corrosion of Light Alloys. This section was devoted to work carried out at the Royal Aircraft Establishment, Farnborough, Hants. L. Takowski gave a paper on the influence of surface contamination on the corrosion of magnesium-manganese alloy sheet. Two papers by L. F. le Brocq and H. G. Cole dealt with corrosion problems arising from the use of magnesium alloys in aircraft and the importance of chemical buffering in the treatments of these alloys. II. METALLURGY. These sessions covered a wide field including various aspects of the production of iron and steel and papers on creep and fatigue.—ALL.

Corrosion of Metals. Part VIII—Aluminum and Its Alloys. Part IX—Magnesium and Its Alloys. "Electron." *Sheet Met. Ind.*, **25,** Nos. 249, 251, 135-142, 541-546 (1948) Jan., March. In progress.

The January installment completes treatment of aluminum and its alloys, covering corrosion fatigue; resistance to sea-water and atmosphere and in food and chemical industries; designing for corrosion resistance; cladding and electrochemical protection. March installment commences account of magnesium and alloys: galvanic corrosion and its relation to design, stress-corrosion, corrosion fatigue.—BNF.

Corrosion: Summary of the Work of the Joint Committees. J. C. Hudson, *Iron & Steel,* **20,** 507 (1947) Nov.; *J. Brit. Shipbuilding Res. Assoc.*, **2,** No. 12, 464 (1947).

Work of the Protective Coatings Sub-Committtee of the Steel Res. Assoc. indicates that preparation of the base surface is the most important factor in the life of protective paints. On well prepared surfaces there is no distinction in the use of inhibitive and non-inhibitive primers, but use of inhibitive primers is of increasing value with lack of base preparation. Marine Corrosion Sub-Committee work confirms this conclusion. A formula is given which is considered to set a standard of reliability for paints for ship hulls. The work of other sub-committees is described and references are given to relevant papers

and reports of the Iron & Steel Institute.—RPI.

Corrosion. Mars G. Fontana, *Ind. & Eng. Chem.*, **40**, 75A, 77A (1948) Mar.

Describes concentration-cell corrosion. Also outlines NACE technical program to be presented in St. Louis, April 5-8, 1948.—BLR.

Corrosion-Resistant Metals for Valves and Seats on Heavy-Duty Engines. A. T. Colwell, Thompson Products, Inc., Paper before SAE Summer Mtg., French Lick, June 2, 1947; *SAE Quarterly Trans.*, **2**, No. 1, 84-103 (1948) Jan.

Valve and seat materials for heavy-duty engines are discussed in great detail, including hard-facing materials. Design aspects are also covered. Among gas turbine bucket materials being evaluated for possible valve use, Inconel X offers great promise. In test to date, seating properties have not been equal to Stellite facing, and it appears deficient in bearing qualities for seat and stem, but stem can be hard-plated and it has performed satisfactorily up to 1500° F. In an aircraft exhaust valve shown, base is of TPA austenitic steel (14nickel-14chromium- 0.50molybdenum-2.5tungsten), with Nichrome head coating, Stellite seat, nitrided stem, tool-steel tip. Valve has a sodium-cooled hollow head and handles up to 150 hp. It will give several thousand hours normal operation. Nimonic 80 has been used to a limited extent for aircraft valves. Field results sometimes disagree with laboratory tests, e.g., lab tests on TPA steel were not impressive, whereas it gave good results in engines. Nichrome puddled seat of a TPA aircraft valve worked well, but when entire valve was of Nichrome, seating was poor. Sigmaphase steel is satisfactory for valves. Hot corrosion tests under stress are the best corrosion tests. Tables include: compotion of turbine alloys, rupture, creep and endurance properties of the latter; compositions of hard-facing materials, composition of seat-insert materials, Brinell hardness and coefficient of linear expansion, room temperature to 1000° F. Graphs show: results of corrosion tests of exhaust-valve steels after 1 hr. at 1675° F.; hot hardness up to 1400° F.; endurance and corrosion tests results with hard facing materials. Various design influences on valve-head temperatures are discussed and illustrated. A positive valve rotator and examples of wear, fatigue, stuffing and deposits on various valve parts and materials are shown.

INHIBITORS

Field Test of Corrosion Inhibitor for Low-pH Flood Water. J. N. Breston and Kenneth Barton, *Oil and Gas J.*, **46**, 91-92, 95-96 (1947) Dec. 6; *Producers Monthly*, **12**, 13-17 (1947) Nov.

Describes new chemical method for protecting water lines from corrosion by slightly acid air-free flood waters, without having to raise the pH. It is accomplished by use of certain amine-type chemicals in concentrations of only a few parts per million. A method also is presented for testing the corrosivity of water and the effectiveness of corrosion inhibitors. It involves insertion of metal coupons into the water lines or bypass lines by means of a plastic coupon holder. Average weight loss is used to calculate relative corrosion. Field tests with rosin Amine acetate (2-4 ppm.) reduced relative corrosivity from 50 to 85 percent.

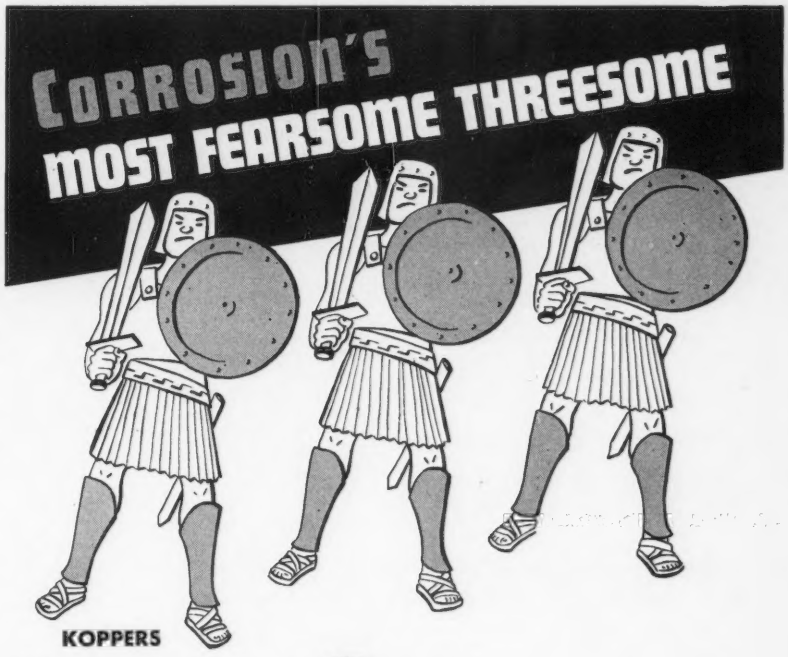
INSPECTION

An Electrolytic Thickness Tester for Plated Metal Coatings. Howard T. Francis, *J. of the Electrochem. Soc.*, **93**, 79-83 (1948) Mar.

Describes device based on anodic dissociation of a defined area of the plated metal, using the current-time product as a measure of the thickness. Successfully measured coatings include: Tin, zinc, lead, cadmium, copper, chromium, silver, gold, and brass on steel; and tin, zinc, lead, and chromium on brass or copper 30 micro-in. of tin on steel can be measured with an accuracy of ±2%. —BLR.

Supersonic Inspection for Internal Fissures in Cast Rolls. J. Dugan, Ohio Steel Foundry Co., *Steel*, **121**, No. 4, 80-81+ (1947) July 28.

The nature of internal fissures in cast steel rolls is discussed briefly and their detection by means of the reflectoscope instrument described at length. Exact location of fissures on interiors of rolls, with not more than 2 percent carbon content, up to 18 feet long and the transverse size and shape of the ruptures can be determined in this way. Experience in the Ohio Steel Foundry is cited. Full description of instrument. Up to the present, no success has been had with supersonic testing of iron base rolls.—INCO.



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METAL FAILURE

Recent Developments in Corrosion-Resistant Aluminum-Magnesium Alloys. P. Brenner and W. Roth, *The J. of the Inst. of Met.* (England) **74,** Part 4, 159-189 (1947) Dec.

The paper describes an extensive investigation on the influence of chemical composition and thermal treatment on the intercrystalline corrosion of aluminum-magnesium alloys containing 5-9 percent magnesium. As a result of the investigation, a new method of heat-treatment, termed a "stabilizing treatment," is suggested in which the alloy is extremely slowly cooled from the homogenizing temperature at a rate of about 50° C./hour. Corrosion tests in the laboratory and in the North Sea, as well as long-term service trials, indicate that alloys treated by this method are immune to intercrystalline-corrosion and stress-corrosion failure even at the high temperatures encountered under tropical conditions. While cold reduction generally increases the tendency to intercrystalline corrosion, small additions of copper, manganese, chromium, and zinc have very different effects. Some of these additions, eg., copper, reduce the stress-corrosion-resistance in the homogenized state and improve it in the aged condition. The high stress-corrosion-resistance of alloys containing small additions of chromium instead of the usual manganese is of special interest. The close correlation between the thermal treatment, the microstructure, and the susceptibility to intercrystalline corrosion, and especially, stress-corrosion of these alloys is clearly indicated. Authors do not differentiate between failure due to general corrosion and those due to rapid penetration charasteristic stress-corrosion. Thirty-five references.—ALL.

Peel on Whiteheart Malleable Cast Iron. J. S. Bowden, *J. of the Iron and Steel Inst.*, **158,** 9-14 (1948) Jan.

Describes development of tests to detect peel on track links and on other castings which were to be used without machining. Experiments devised to determine conditions under which peeling takes place are described. A theory is advanced that peel formation occurs by preferential oxidation of the silicon in the metal to form fayalite when the CO/CO_2 ratio in the malleableizing atmosphere is abnormally high. It is also demonstrated that peel can be produced on silicon-manganese steel.—BLR.

Some Model Experiments on the Effect of Blade Area on Propeller Cavitation. L. C. Bell, Paper before Inst. Naval Architects, *Engineering,* **164,** 331-332 (1947) Oct. 3.

Describes results of tests on 6 three-bladed propellers, of destroyer type, carried out in the cavitation tunnel put into service at Haslar in 1942. Discussion on the vortex character of the laminar cavitation is given.—INCO.

Study of Black Streaks Produced on the Skin or Cloth from the Wearing of Gold Jewelry. (In French) Marcel Ballay and Pierre Vogt, *R. de Metallurgie,* **44,** 256-260 (1947) July-Aug.

Jewelry of various types was tested on numerous wearers and under controlled conditions to determine the reason for the above streaks. It was found that there is less effect from solid pieces than from chains or other cutwork and that it is caused by the abrasive action of dust and other foreign matter, not by corrosion caused by reaction with skin secretions.—BLR.

Ferrous Physical Metallurgy. M. Baeyertz and W. F. Craig, Jr., *Mining and Metallurgy,* **29,** 114-117 (1948) Feb.

Reviews 1947 developments in mechanical properties; transformations; quenching and heat flow; magnetic and electrical properties; and corrosion.—BLR.

Failure of Metals by Fatigue. *Iron & Coal Trades Rev.,* **154,** 463-467 (1947) Mar. 21; *Corros. & Matl. Prot.,* **4,** No. 5, 21 (1947) Sept.-Oct.

Abstracts of a series of papers comprising a symposium held at the University of Melbourne. Considers various causes of fatigue corrosion.—INCO.

Stress Corrosion Cracking of Welded Mild Steel Gas Mains. *Committee Brit. Welding Res. Assoc., Chem. & Ind.,* No. 36, 549 (1947) Sept. 6; *J. Iron & Steel Inst.,* **157,** Pt. I, 136-137 (1947) Sept.

Summary of present position on results of investigations to date into stress corrosion cracking of welded mild steel gas mains by industrial and university laboratories as well as Gas Research Board and British I. and S. Res. Assoc. Failure has occurred only in portion of gas plant after condensation and prior to ammonia extraction. The failure is identified as a particular case of intercrystalline cracking. Differences in welding technique do not influence the incidence of cracking. It is believed that stress-relieving or shot-blasting may solve the problem, but the method of procedure will have to be accurately ascertained. Oxidation products of ammoniacal liquors constituents are an important factor. Field experiments covering various types of steels and other factors instituted in gas works will be evaluated in conjunction with laboratory tests.—INCO.

Corrosion Cracking of Magnesium Alloys. (In Russian.) E. M. Zaretskii, *Zhurnal Prikladnoi Khimii (J. Applied Chem.),* 823-829 (1947) Sept. 20.

The corrosion resistance of 1 mm. sheet containing 5.62-5.84% aluminum; 0.95% zinc; 0.38% manganese; 0.09% silicon, and 0.05% magnesium was investigated under conditions of tensile stress and at temperatures from room to 420° in air and in various other media. Attempts to improve stress-corrosion resistance by cold working or heat treatment were unsuccessful.—BLR.

Corrosion Cracking of Cast Magnesium Alloys. (In Russian.) E. M. Zaretskii *Zhurnal Prikladnoi Khimii (J. Applied Chem.),* 830-840 (1947) Sept. 20.

Stress corrosion resistance of cast magnesium, of the alloy mentioned in the above abstract, and of another one containing 10% aluminum; 0.20% manganese; 0.04% iron, and 0.09% silicon were investigated. The first was not sensitive to stress corrosion; the cast form of the second, contrary to the cold-worked form, is also not sensitive; the latter cast alloy has a slight tendency toward stress corrosion, which can be eliminated by proper heat treatment and quenching procedure, which is described. The mechanism of stress corrosion in cold-worked and cast magnesium alloys is explained. 12 ref.—BLR.

Caustic Cracking of Welded Steel Plate. H. M. Wilten, *Metal Prog.,* **52,** 803-805 (1947) Nov.

Discusses above type of failure, which is said to be very rare. Presents results of an investigation of the failure, photomicrographs included.—BLR.

Peeling of Whiteheart Malleable Iron. G. R. Webster & A. E. Probst, *J. Iron & Steel Inst.,* **158,** 15-19 (1948) Jan.

Peeling, as distinct from sealing, is described, and examples of the defect are given and discussed. Experiments with malleable iron of varying thicknesses and with various sulfur contents have shown that a high sulfur content in the iron ore used for malleableizing causes peeling.—BLR.

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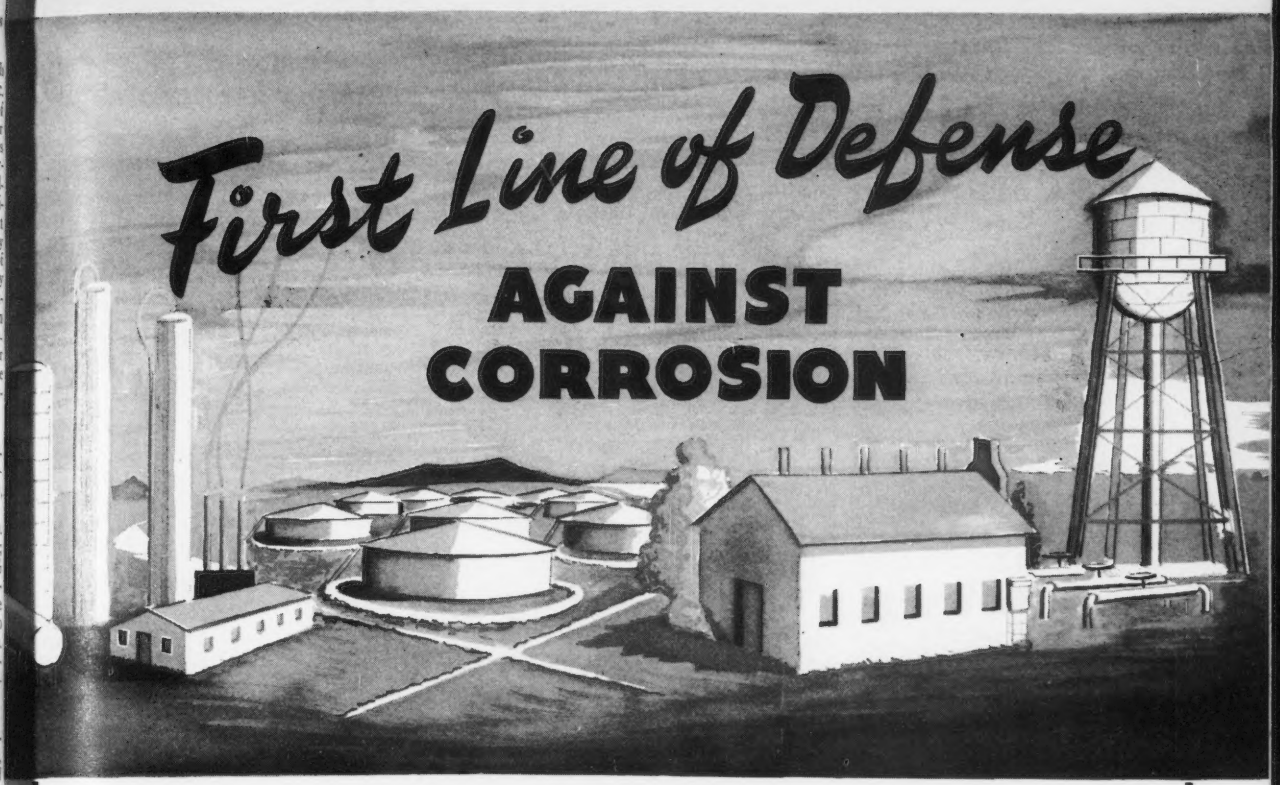

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WATER CORROSION

Corrosion in Boiler Feedwater Treating Systems. IV. Leo F. Collins, *Power Generation*, **52**, No. 1, 106-108 (1948) Jan.

Last of four installments. Reports tests to evaluate comparative corrosion resistance of materials used in deaerating heater trays, vent condenser tubes, water heater tubes. For heating trays, the following was noted: (1) Gray iron corrodes at a rate slightly higher than any of the other materials. (2) Parkerizing did not materially change the corrosion characteristics of the cast iron. (3) Copper bearing and nitrided steels exhibited about the same corrosion resistivity as cast iron. (4) Erosion, rather than corrosion, of aluminum trays was pronounced at the holes and rendered them obsolete in three years. (5) Brass was also susceptible to erosion, but not to the same extent as aluminum. The brass trays were discarded after about six years. (6) Glazing was removed from tile-trays after one year. In some instances they cracked during operation. In general they required such careful handling as to be judged impractical. (7) Cadmium plating disappeared in one year of service. (8) Sheet lead coatings blistered and peeled in second year of operation. (9) The alloyed cast irons showed no marked superiority over gray iron. From these observations, it was concluded that, on a service-per-dollar basis, gray iron is the logical choice, recognizing that periodic replacements will be necessary. As for tubes and tube sheets, used on vent condensers of a deaerating feedwater heater, it was shown that tinning the copper alloys very greatly reduced corrosion. The corrosion rate for copper alloys in hot, hard water is about one-fifth that for the same materials exposed to condensate from a vent condenser. For steel, increasing the temperature of hard water from the range of 40-60° F. to 120-150° F. increased the corrosion rate about eightfold.—CEC.

Galvanic Corrosion of Dissimilar Metals as Applied to Gas Hot Water Storage Heaters. Part I. Robert C. Weast, *Am. Gas. Assoc.*, 23 pp. (1947) Dec.

Describes test results obtained from a small-scale installation in an effort to obtain criteria for evaluating corrosion inhibitors.—BLR.

Gage-Glass Condensate Cracks Metal by Pocketing at Drum Counterbore. J. A. Keeth, Kansas City Power and Light Co., Paper before NACE, Ann. Mtg., Kansas City, May, 1946, *Power*, **91**, No. 8, 78-79, (1947) Aug.

Discussion of how one plant licked corrosive fatigue by revamping drum connections so that the returning condensate diffused into the boiler water instead of remaining undiluted in the Counterbore where it had caused cracking.—INCO.

Corrosion. D. H. Garside, *Ind. Heat Eng.*, **9**, No. 34, 47-50 (1947); *Railway Eng. Absts.*, **2**, No. 9, 230 (1947).

Protection of pipes carrying water, hot air, steam, etc., is considered, and among other methods, painting, particularly with silicone and other synthetic resin lacquers is discussed.—RPI.

Hot Water Corrosion of Zinc—I. Rapid Testing by Means of Dithizone. II. (Effect of Temperature). H. Grubitsch, J. Sinigo & O. Illi, *Korros. u. Metallschutz*, 16, 194-203 (1940); *Brit. Abstrs.*, **BI**, 142 (1947) April.

The true initial rate of reaction of zinc with hot water (as determined by rotating a pure zinc specimen in double-distilled water for short intervals and estimating the colloidal corrosion products by the dithizone method) and the increase in rate of corrosion of zinc in water with rise in temperature up to 60° C. and its subsequent decrease were investigated. Below 60° C. the corrosion process is limited by the reactions $Zn + H_2O = Zn(OH)_2 + H_2$ and $2H + \frac{1}{2}O_2 = H_2O$. Above 60° C. the limiting reaction is either $Zn(OH)_2 = ZnO + H_2O$ or $Zn + \frac{1}{2}O_2 = ZnO$. At low ($O_2$) the maximum corrosion velocity is displaced from 60° C. to lower temperatures.—INCO.

Corrosion in Boiler Feedwater Treating Systems—I, II, III. L. F. Collins, Detroit Edison Co., *Power Plant Eng.*, **51**, No. 10, 74-76 (1947) Oct.; No. 11, 114-116, Nov.; No. 12, 114-116, 132, Dec.

Data are presented on boiler feedwater treating systems to better design and operation. Part I shows pattern of corrosion in zeolite-acid-degasification system. Procedures outlined by Langelier provide reliable means for approximating corrosivity of different types of water involved. Corrosion reaches max. at deaerator vent condenser. Part II analyzes graphitic corrosion in such systems and describes laboratory tests of cast iron test bars and field observations. In zeolite-acid water treatment systems, quiescent soft waters laden with O_2 are most conductive to graphitic corrosion of gray iron. Part III deals specifically with suitable materials for primary equipment and for use in acid and brine systems. In vent boxes, cast iron lasted 10 years, 4 nickel-7 copper-cast iron lasted seven years. Type 302 stainless was unattacked after seven years. Painted steel is best for sodium unit of zeolite softeners. Copper-rich brasses are preferred over yellow brasses in regenerant manifolds. Invent condenser "hot ends," 80-20 copper-nickel lasted four years, aluminum-bronze six, arsenical copper five, and Admiralty 4 to 10 years, attack being on seam side. Vent condenser shells tin-coated on the wet side by double-dip hot process method are preferable to cast iron or steel. Stainless may also be suitable. Where alkaline waters are involved, either cast iron or common steel are used for shells of deaerating feedwater heaters. Welded steel brine tanks are suitable for transporting and storing strong H_2SO_4 if precautions are taken to prevent absorption by acid of significant amounts of moisture. Lead or rubber lined steel is recommended for phosphoric acid. Lead-lined steel piping is preferred for dilute acids and copper for concentrated brine. —INCO.

Effect of Fire Scale on Interior Corrosion of Boiler Tubes. H. C. Dinger, U. S. Navy, *Marine Eng.*, **52**, No. 12, 73 (1947) Dec.

Presence of scale on the outside of a boiler tube has an effect upon the interior tube surface under special conditions. Outside scale causes overheating or hot spots which accelerate corrosion action. This is caused by a rise in temperature of the metal in contact with the water. Uniform scale coating retards transfer of heat but a variable one caused by scale dropping off in places

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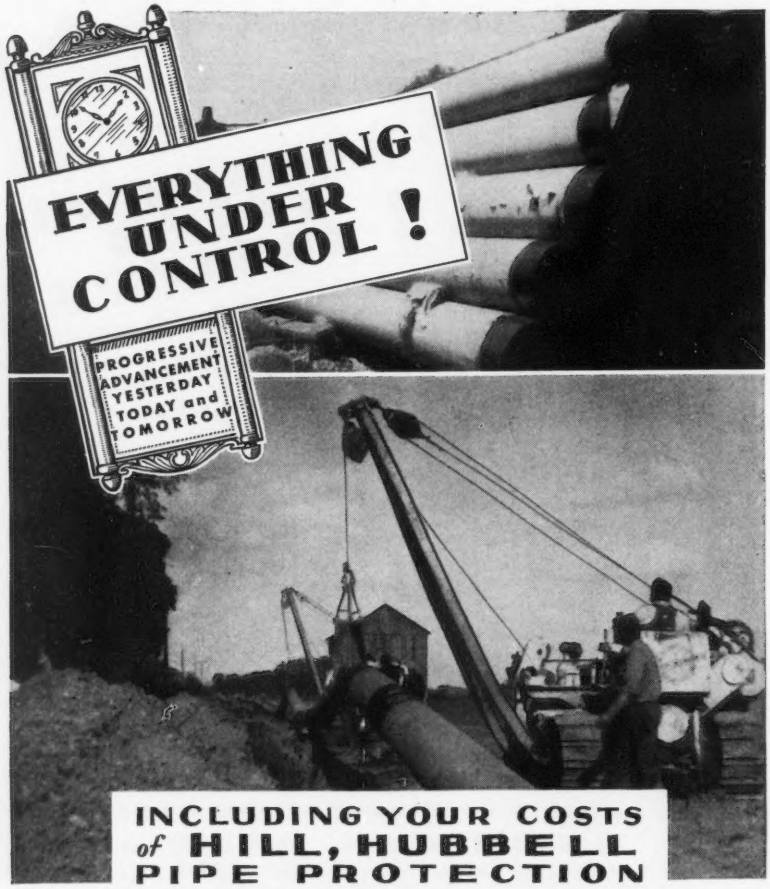
or by having special deposits on certain localities will cause a variation in the tube temperature which may set up corrosive action in addition to stress due to temperature differences. With clean boiler water, properly treated, this destructive action is unlikely but when there are dirt spots or adherent scale and inadequate treatment the higher temperature of the metal at the hot spot may initiate action which would not take place at normal temperature.—INCO.

Corrosion in Boiler Feedwater Treating Systems—IV. (Concluded). Leo F. Collins, *Power Generation*, **52**, 106, 108 (1948) Jan.

Refers especially to systems employing zeolite, acids, and degasification. Presents results of tests made to evaluate comparative corrosion resistance of materials used in deaerating heater trays, vent condenser tubes, and water-heater tubes.—BLR

Corrosion Prevention by Controlled Calcium Carbonate Scale. Sheppard T. Powell, H. E. Bacon & E. L. Knoedler, *Ind. & Eng. Chem.*, **40**, 453-457 (1948) Mar.

Use of the above for corrosion prevention in cooling-tower systems serving steel equipment was discussed in an earlier paper. New data for the ionization constants of carbonic acid have been used to recalculate the pH-temperature curves, to bring them up to date. 10 ref. —BLR.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MAPLEWOOD

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CARMICHAEL, Elwood T., Public Service Electric & Gas Co., 80 Park Place.
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JACKSON, C. M., Devoe & Raynolds Co., Rutherford & Delancey Sts.
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RANDOLPH, A. F., Public Service Electric & Gas Co., 80 Park Place.
SALMON, Philip A., Public Service Electric & Gas Co., 80 Park Place.
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PASSAIC

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PATERSON

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GARRISON, V. L., Okonite Callender Cable Co., Inc., 730 21st Ave.
REINITZ, Bernard B., Okonite Callender Cable Co., 730 21st Ave.

PENNS GROVE

DEGNAN, Thomas F., E. I. duPont De Nemours & Co., Chambers Works.

PHILLIPSBURG

CANN, Kenneth R., Ingersoll-Rand Co.
GODSHALL, J. Byron, Ingersoll-Rand Co.

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ALFKE, C. J., Hackensack Water Co., 4100 Park Ave.

W. ENGLEWOOD

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WESTFIELD

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PITTMAN, Charles U., Koppers Co.
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HOLT, James B., International Minerals & Chemical Corp.
SMITH, Randal E., Potash Company of America, Box 31.

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DIEHLMAN, George, Research Laboratories, National Lead Co., 105 York St.
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SHAW, William E., National Lead Co., 105 York St.
THOMPSON, Charles H., New York Telephone Co., 101 Willoughby St.
WILKINSON, Horatio L., The Debevoise Co., 968 Grand St.

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NEUHAUS, Richard, Nukem Products Corp.
NICHOLSON, C. T., Buffalo Niagara Electric Corp., Electric Bldg.
SMITH, Walter R., Nukem Products Corp., 111 Colgate Ave.

HASTINGS-ON-HUDSON

BURD, Harry G., Anaconda Wire & Cable Co.

HICKSVILLE

YAHNKER, W. F., The Glasfloss Corp., New South Rd.

LOCKPORT

WALKER, Hiram, Harrison Radiator Div., General Motors Corp.

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NEW YORK

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ANDREW, Harold O., Moore-Robbins Publishing Co., Inc., 9 E. 38th St.
AYRES, Robert Finley, Oakite Products, Inc., 22 Thames St.
BAGNELL, William E., Ebasco Services, Inc., 2 Rector St.
BAKER, Ralph D., National Lead Co., 111 Broadway.
BALDWIN, L. A., Johns-Manville Sales Corp., 22 E. 40th St.
BATTLE, Thomas J., Koppers Co., Inc., New York, N. Y. For mail: 629 W. 115th St.
BEBBINGTON, Marguerite, International Nickel Co., Inc., 67 Wall St.
BECKER, Wm. D., Burns & Roe, Inc., 233 Broadway.
BENNETT, A. T., Mathieson Chemical Corp., 60 East 42nd St.
BOYD, George E., Koppers Co., Inc., 350 Fifth Ave.
BREMER, Clarence, Oakite Products, Inc., 22 Thames St.
BRITTON, H. B., Middle East Pipe Line Co., 25 W. 45th St.
BRULEY, Robert W., Koppers Co., Inc., 17 Battery Place.
CARR, Reid L., Columbian Carbon Co., 41 E. 42nd St.
CHAMPLIN, George D. L., Standard Oil Development Co., 15 W. 51st.
COURT, W. F., Shell Oil Co., Inc., 50 W. 50th St.
COWART, B. C., Barrett Div., Allied Chemical & Dye Corp., 40 Rector St.
DEVOLUY, Raymond, C. A. Woolsey Paint & Color Co., Inc., 229 E. 42nd St.
DEWEY, Wm. S., New York Telephone Co., 140 West St.
DICKINSON, L. R., Socony-Vacuum Oil Co., Inc., 26 Broadway.
DONOVAN, Lewis B., Consolidated Edison Company of New York, Inc., 4 Irving Place.
EVANS, Clair O., Phelps Dodge Copper Products Corp., 40 Wall St.
EVERETT, Ralph H., M. J. Merkin Paint Co., Inc., 1441 Broadway.
FAIRES, Carl D., Shell Oil Co., Inc., 50 W. 50th St.
FARABAUGH, Cletus F., Pennsylvania & Long Island Railroads, Pennsylvania Station.
FARKAS, Howard, The U. S. Stoneware Co., 60 E. 42nd St.
FELLER, Eugene W. F., McGraw-Hill Publishing Co., 330 W. 42nd St.
FETTER, Edmond C., Chemical Engineering, 330 W. 42nd St.
FLENTJE, Martin E., American Water Works Co., 50 Broad St.
FORREST, Matthew G., Gibbs & Cox, Inc., 21 West St.
FOSTER, Albert C., Standard Brands, Inc., 595 Madison Ave.
FRIEND, W. Z., International Nickel Co., Inc., 67 Wall St.
FRIZ, Nelson, Standard Oil Company of New Jersey, 26 Broadway.
GEHLEN, Carl, E. I. duPont De Nemours & Co., 350 Fifth Ave.
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JOHNSTON, Howard E., Dearborn Chemical Co., 205 E. 42nd St.
JORDAN, Harry E., American Water Works Association, 500 Fifth Ave.
KELLOGG, Markoe O., Shell Oil Co., Inc., 50 W. 50th St.
KLEIN, Fred. M., Maurice A. Knight Co., 55 W. 42nd St.
KNOWLTON, A. E., Electrical World, 330 W. 42nd St.
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LANG, Franklin, Feedwaters, Inc., 140 Cedar St.
LaQUE, F. L., International Nickel Co., Inc., 67 Wall St.
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LUNDBERG, Harry E., The Dorr Co., 570 Lexington Ave.
MACK, Bernard, Sam Tour & Co., Inc., 44 Trinity Place.
MAITLAND, T. J., American Telephone & Telegraph Co., 32 Sixth Ave.
MARSHALL, Dwight, St. Joseph Lead Co., 250 Park Ave.
MASON, John F., Jr., International Nickel Co., Inc., 67 Wall St.
MAURER, Keith L., Bell Telephone Laboratories, Inc., 463 West St.
MAY, Thomas P., International Nickel Co., Inc., 67 Wall St.
MOE, John L., Ebasco Services, Inc., 2 Rector St.
MORSE, Robert E., American Gas & Electric Service Corp., 30 Church St.
MORTON, Byron B., International Nickel Co., Inc., 67 Wall St.
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PLACE, George W., American Bureau of Shipping, 45 Broad St.
POPE, Robert, Bell Telephone Laboratories, 463 West St.
PRIESTLEY, Henry L., Electro Metallurgical Co., 30 E. 42nd St.
RHODES, George I., Ford, Bacon & Davis, Inc., 39 Broadway.
RIDDICK, Thomas M., Consulting Engineer & Chemist, 369 E. 149th St.
RINEHART, Evan, Johns-Manville, 22 E. 40th St.
RIPPIE, Charles W., Lukens Steel Co., 50 Church St.
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SAMPLE, Clarence H., International Nickel Co., Inc., 67 Wall St.
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SCAROLA, V. J., Tapecoat Co., 489 Fifth Ave.
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SMITH, Sydney S., Shell Oil Company, Inc., 50 W. 50th St.
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TICE, E. Allen, International Nickel Co., 67 Wall St.
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SHIELDS, James E., Alox Corp., 3943 Buffalo Ave.
THORNBERG, Joseph E., Hooker Electrochemical Co., 47th St. & Buffalo Ave.
VAN HORNE, Roger H., Hooker Electrochemical Co., Buffalo Ave. & 47th St.

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MACCOLLUM, Donald R., Rochester Gas & Electric Corp., 89 East Ave.
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BRONSTEIN, Emanuel H., The Ric-Wil Co.
GEGNER, Paul J., Pittsburgh Plate Glass Co., Columbia Chemical Div.

CANTON

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MIDDLETOWN

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HALBIG, John J., Armco Steel Corp.
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PAINESVILLE

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TOLEDO

CALLAWAY, C. C., Jr., Owens-Corning Fiberglas Corp., Nicholas Bldg.

WATERVILLE

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YOUNGSTOWN

FETTERS, Karl L., The Youngstown Sheet & Tube Co., Stambaugh Bldg.
FLICKINGER, L. C., The Youngstown Sheet & Tube Co., Campbell Works.
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REINHARDT, G. A., Youngstown Sheet & Tube Co.

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DEWAR, J. S., H. C. Price Co., Box 1111.
EILERTS, C. Kenneth, Bureau of Mines.
FLEMING, M. C., Phillips Petroleum Co.
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CUSHING

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ENID

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GOINS, Vernon D., Tuboscope Company, 2629 N. W. 37th St.
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VOLKENING, V. B., Dow Chemical Co.
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ALLIED CHEMICAL & DYE CORP., Barrett Div.	New York, N. Y.	B. C. Cowart
ALLOY STEEL PRODUCTS COMPANY	Linden, N. J.	E. G. Holmberg
ALUMINUM COMPANY OF AMERICA	New Kensington, Pa.	E. D. Verink, Jr.
AMARILLO OIL COMPANY	Amarillo, Tex.	A. F. Cox
AMERICAN BRASS COMPANY, THE	Waterbury, Conn.	John R. Freeman, Jr.
AMERICAN GAS & ELECTRIC SERVICE CORP.	New York, N. Y.	R. E. Morse
AMERICAN PETROLEUM COMPANY	Houston, Tex.	G. O. Irvine
AMERICAN PIPE & CONSTRUCTION COMPANY, Amercoat Division	South Gate, Calif.	C. G. Munger
AMERICAN STEEL & WIRE COMPANY	Cleveland, Ohio	H. H. Febrey
AMERICAN TELEPHONE & TELEGRAPH COMPANY	New York, N. Y.	J. M. Standring
ANGLO-IRANIAN OIL COMPANY, LTD.	New York, N. Y.	B. R. Jackson
APEX SMELTING CO.	Chicago, Ill.	A. J. Peterson
ARKANSAS FUEL OIL COMPANY	Shreveport, La.	L. F. Babcock
ARKANSAS LOUISIANA GAS COMPANY	Shreveport, La.	W. A. Broome
ARKANSAS POWER & LIGHT COMPANY	Pine Bluff, Ark.	W. A. Green
ASSOCIATED CONTRACTORS & ENGINEERS	Houston, Tex.	A. L. Forbes, Jr.
ATCHISON, TOPEKA & SANTA FE RAILROAD CO.	Chicago, Ill.	E. E. Chapman
ATLANTIC REFINING COMPANY—Refining Div.	Philadelphia, Pa.	J. K. Deichler
ATLANTIC REFINING COMPANY—Producing Div.	Philadelphia, Pa.	B. E. Moir
BART MANUFACTURING COMPANY	Belleville, N. J.	S. G. Bart
BASTIAN-MORLEY COMPANY, INC.	La Porte, Ind.	H. B. Carbon
BATAAFSCHE PETROLEUM MAATSCHAPPIJ, N. V. DE	The Hague, Holland	J. H. G. Post
BECHTEL CORP.	San Francisco, Calif.	J. S. Connell
BELL TELEPHONE LABORATORIES, INC.	New York, N. Y.	Robert Pope
BETHLEHEM STEEL COMPANY	Bethlehem, Pa.	S. C. Frye
BIRMINGHAM GAS COMPANY	Birmingham, Ala.	Chas. B. Gamble
BLACK-CLAWSON COMPANY, THE	Hamilton, Ohio	John D. Sheley
BRANCE-KRACHY COMPANY, INC.	Houston, Tex.	Wayne E. Broyles
BRIGGS BITUMINOUS COMPOSITION COMPANY	Philadelphia, Pa.	J. D. Farber
BULLDOG ELECTRIC PRODUCTS COMPANY	Detroit, Mich.	James Unger
BYERS, A. M., COMPANY	Pittsburgh, Pa.	J. W. Marrinan
BYRON JACKSON COMPANY	Los Angeles, Calif.	M. B. Riordan
CALIFORNIA COMPANY, THE	New Orleans, La.	E. M. Kipp
CAMERON IRON WORKS, INC.	Houston, Tex.	Jack W. Harris
CANADIAN RIVER GAS COMPANY	Amarillo, Tex.	W. M. Clifton
CANADIAN WESTERN NATURAL GAS CO., LTD.	Calgary, Alberta, Canada	B. W. Snyder
CARNEGIE-ILLINOIS STEEL CORP.	Pittsburgh, Pa.	R. B. Mears
CELANESE CORPORATION OF AMERICA	New York, N. Y.	S. B. Roberts
CENTRAL ELECTRIC & GAS COMPANY	Lincoln, Neb.	E. P. Hennek
CENTRAL NEW YORK POWER CORP.	Syracuse, N. Y.	J. E. Cooper
CENTRAL POWER & LIGHT COMPANY	Corpus Christi, Tex.	Geo. A. Mills
CHAMPLIN REFINING COMPANY	Enid, Okla.	E. G. Wilmoth
CHANSLOR-CANFIELD MIDWAY OIL COMPANY	Los Angeles, Calif.	H. L. Briggs
CHATTANOOGA GAS COMPANY	Chattanooga, Tenn.	H. R. Derrick
CHESAPEAKE & OHIO RAILWAY CO.	Richmond, Va.	C. B. Hitch
CHICAGO BRIDGE & IRON COMPANY	Chicago, Ill.	Fred L. Goldsby
CINCINNATI GAS & ELECTRIC COMPANY	Cincinnati, Ohio	M. J. Pfeiffer
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CITIES SERVICE REFINING CORP.	Lake Charles, La.	L. D. Mann
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COLORADO INTERSTATE GAS COMPANY	Colorado Springs, Colo.	C. B. Abbot
COLUMBIA ENGINEERING CORP.	Columbus, Ohio	C. F. de Mey
COLUMBIAN CARBON COMPANY	New York, N. Y.	Reid L. Carr
COLUMBUS & SOUTHERN OHIO ELECTRIC CO.	Columbus, Ohio	F. H. Streit
COMMONWEALTH EDISON COMPANY	Chicago, Ill.	Alex D. Bailey
CONSOLIDATED EDISON CO. OF NEW YORK, INC.	New York, N. Y.	L. J. Gorman
CONSOLIDATED GAS ELECTRIC LIGHT & POWER CO. OF BALTIMORE	Baltimore, Md.	T. J. Dwyer
CONSUMERS POWER COMPANY	Jackson, Mich.	D. E. Herringshaw
CONTINENTAL OIL COMPANY	Ponca City, Okla.	A. C. Wilkinson

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CORN PRODUCTS REFINING CO., Chemical Div.	Argo, Ill.	R. W. Flournoy
COSDEN PETROLEUM CORP.	Big Spring, Tex.	R. W. Thompson
CRANE CO.	Chicago, Ill.	L. G. Vande Bogart
CREOLE PETROLEUM CORP.	Caracas, Venezuela, S. A.	F. J. Amador
CRUTCHER-ROLFS-CUMMINGS, INC.	Houston, Tex.	E. L. Rolfs
DALLAS POWER & LIGHT COMPANY	Dallas, Tex.	Robert D. Elliott
DEARBORN CHEMICAL COMPANY	Chicago, Ill.	E. M. Converse
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DOUGLAS AIRCRAFT CO.	Santa Monica, Calif.	F. T. Wood, Jr.
DOW CHEMICAL COMPANY	Midland, Mich.	Arthur Smith, Jr.
EAST OHIO GAS COMPANY, THE	Cleveland, Ohio	F. E. Vandaveer
EASTERN STATES PETROLEUM CO., INC.	Houston, Tex.	Ewald A. Roesler
EBASCO SERVICES, INC.	New York, N. Y.	M. C. Miller
ELECTRO RUST-PROOFING CORP.	Belleville, N. J.	R. T. Browning
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EMPIRE PIPE LINE COMPANY	Bartlesville, Okla.	Clay Briggs
ETHYL CORPORATION	Baton Rouge, La.	C. C. Harvey
FEDERAL TELEPHONE & RADIO CORP.	Newark, N. J.	H. W. Mason
FERRO ENAMEL CORP.	Cleveland, Ohio	G. H. McIntyre
FISH ENGINEERING CORP., THE	Houston, Tex.	Paul Hall
FLINTKOTE COMPANY	New York, N. Y.	Frank H. Neher
FLORIDA POWER & LIGHT COMPANY	Miami, Fla.	C. H. Summers
FRUEHAUF TRAILOR COMPANY	Detroit, Mich.	F. M. Reid
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GOOD-ALL ELECTRIC MANUFACTURING CO.	Ogallala, Neb.	R. A. Goodall
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GREAT LAKES PIPE LINE COMPANY	Kansas City, Mo.	C. C. Keane
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GUTHRIE GAS UTILITIES COMPANY	Guthrie, Okla.	Merle W. Bahan
HACKENSACK WATER COMPANY	Weehawken, N. J.	C. J. Alfke
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HERCULES POWDER COMPANY	Wilmington, Del.	R. F. Schultz
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HOUSTON PIPE LINE COMPANY	Houston, Tex.	C. Lee Wood
HUMBLE OIL & REFINING COMPANY	Houston, Tex.	H. D. Wilde
HUMBLE PIPE LINE COMPANY	Houston, Tex.	O. Q. Lomax
INTERNATIONAL NICKEL COMPANY, INC., THE	New York, N. Y.	W. Z. Friend
INTERSTATE OIL PIPE LINE CO.	Tulsa, Okla.	J. C. Rawlins
INTERSTATE NATURAL GAS COMPANY, INC.	Monroe, La.	O. C. Roddey
JACOBS WIND ELECTRIC COMPANY, INC.	Minneapolis, Minn.	M. L. Jacobs
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KANSAS-NEBRASKA NATURAL GAS CO., INC.	Hastings, Neb.	Leonard C. Hill
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LACLEDE GAS LIGHT CO.	St. Louis, Mo.	C. E. Schoene
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LEBANON STEEL FOUNDRY	Lebanon, Pa.	E. H. Platz, Jr.
LION OIL COMPANY	El Dorado, Ark.	J. B. Rogerson
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MAGNOLIA PETROLEUM COMPANY	Beaumont, Tex.	C. A. Knight
MAGNOLIA PIPE LINE COMPANY	Dallas, Tex.	D. H. Levy
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McKEE, ARTHUR G. & CO.	Cleveland, Ohio	D. W. Wilson

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MEMPHIS NATURAL GAS COMPANY	Memphis, Tenn.	Fred D. Stull
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MICHIGAN CONSOLIDATED GAS CO.	Detroit, Mich.	T. W. Weigele
MID-CONTINENT PIPE LINE COMPANY	Tulsa, Okla.	F. E. Pyeatt, Jr.
MIDWESTERN ENGINE & EQUIPMENT CO.	Tulsa, Okla.	G. O. Glandon
MISSISSIPPI GAS COMPANY	Meridian, Miss.	H. K. Griffin
MISSISSIPPI POWER & LIGHT COMPANY	Jackson, Miss.	G. C. Jones
MISSISSIPPI RIVER FUEL CORP.	St. Louis, Mo.	G. B. Lowther
MISSOURI-KANSAS-TEXAS LINES	St. Louis, Mo.	K. H. Hanger
MISSOURI PACIFIC R. R. CO., (Guy A. Thompson, Trustee)	St. Louis, Mo.	R. P. Hart
MOBILE GAS SERVICE CORP.	Mobile, Ala.	Harold T. Strange
MONSANTO CHEMICAL CO.	St. Louis, Mo.	F. L. Whitney
MONTANA POWER COMPANY, THE	Butte, Montana	C. R. Davis
MOUNTAIN FUEL SUPPLY COMPANY	Salt Lake City, Utah	Harry R. Brough
MUTUAL CHEMICAL COMPANY OF AMERICA	New York, N. Y.	Geo. E. Best
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NATIONAL SUPPLY COMPANY, Spang-Chalfant Div.	Tulsa, Okla.	H. G. Texter
NATIONAL TANK COMPANY	Tulsa, Okla.	C. O. Glasgow
NATURAL GAS PIPELINE CO. OF AMERICA	Chicago, Ill.	A. F. Schmierer
NEW ORLEANS PUBLIC SERVICE, INC.	New Orleans, La.	L. G. Ireland
NEW YORK & RICHMOND GAS COMPANY	Staten Island, New York, N. Y.	R. Van Vliet
NEW YORK CENTRAL RAILROAD CO., THE	New York, N. Y.	D. B. Thompson
NEW YORK TELEPHONE COMPANY	New York, N. Y.	W. G. Hampton
NOOTER, JOHN, BOILER WORKS COMPANY	St. Louis, Mo.	Walter Meyer
NORTH PENNSYLVANIA GAS COMPANY	Port Allegheny, Pa.	J. H. Isherwood
NORTHERN NATURAL GAS COMPANY	Omaha, Neb.	W. B. Haas
NORTHWESTERN UTILITIES, LTD.	Edmonton, Alberta, Canada	R. C. McPherson
NUKEM PRODUCTS COMPANY	Buffalo, N. Y.	John W. Chandler
OHIO OIL COMPANY, THE	Findlay, Ohio	Ralph M. Slough
OKLAHOMA GAS & ELECTRIC COMPANY	Oklahoma City, Okla.	D. O. Lima
OLIVER UNITED FILTERS, INC.	Oakland, Calif.	E. D. Flynn
OMAHA & COUNCIL BLUFFS ELECTROLYSIS COMMITTEE	Omaha, Neb.	H. W. Bruhn
OWENS-CORNING FIBERGLAS CORP.	Toledo, Ohio	C. C. Calloway, Jr.
PACIFIC GAS & ELECTRIC COMPANY	San Francisco, Calif.	W. R. Schneider
PAN AMERICAN PIPE LINE COMPANY	Houston, Tex.	P. F. Williams
PANHANDLE EASTERN PIPE LINE CO.	Kansas City, Mo.	E. Buddrus
PEOPLES GAS, LIGHT & COKE CO., THE	Chicago, Ill.	L. G. Ranta
PEOPLES NATURAL GAS COMPANY, THE	Pittsburgh, Pa.	C. A. Erickson, Jr.
PERRAULT BROTHERS	Tulsa, Okla.	Lewis Perrault
PETROLEUM ENGINEERING, INC.	Houston, Tex.	Paul M. Raigorodsky
PHILADELPHIA ELECTRIC COMPANY	Philadelphia, Pa.	H. S. Phelps
PHILIP CAREY MFG. COMPANY, THE	Lockland (Cincinnati), Ohio	V. V. Malcom
PHILLIPS PETROLEUM COMPANY	Bartlesville, Okla.	I. B. Tietze
PIPE LINE SERVICE CORP.	Franklin Park, Ill.	A. D. Imes
PITTSBURGH COKE & CHEM. COMPANY	Pittsburgh, Pa.	Russell H. Coe
PITTSBURGH PLATE GLASS COMPANY	Barberton, Ohio	Paul J. Gegner
PLANTATION PIPE LINE COMPANY	Atlanta, Georgia	W. G. Horstman
PLASTIC LINING CORP.	Chicago, Ill.	C. A. Van Natta
PORTLAND PIPE LINE CORP.	Portland, Me.	C. Donald Batchelder
POTASH COMPANY OF AMERICA	Carlsbad, N. Mex.	E. W. Douglass
PREMIER OIL REFINING COMPANY OF TEXAS, Pipe Line Div.	Ranger, Tex.	David D. Pickrell
PRICE, H. C., COMPANY	Bartlesville, Okla.	J. S. Dewar
PUBLIC SERVICE CORP. OF NEW JERSEY	Newark, N. J.	Geo. H. Blake
PUBLIC SERVICE CO. OF NORTHERN ILLINOIS	Chicago, Ill.	E. F. Lungren
PURE TRANSPORTATION COMPANY	Chicago, Ill.	D. C. Glass
REPUBLIC NATURAL GAS COMPANY	Dallas, Tex.	C. C. Book
REYNOLDS METALS COMPANY	Louisville, Kentucky	Geo. Perkins
RICHFIELD OIL CORP.	Los Angeles, Calif.	D. F. Purdy
ROCHESTER GAS & ELECTRIC CORP.	Rochester, N. Y.	E. R. Crofts
ROCKWELL MFG. COMPANY, Nordstrom Valve Div.	Pittsburgh, Pa.	E. E. Matheson

CORPORATE AND ASSOCIATE N.A.C.E. MEMBERS, 1949

SAN DIEGO GAS & ELECTRIC COMPANY	San Diego, Calif.	L. M. Klauber
SCHENLEY DISTILLERS CORP.	New York, N. Y.	G. H. van de Griendt
SCRANTON-SPRING BROOK WATER SERVICE CO.	Wilkes-Barre, Pa.	Rulison Evans
SHAMROCK OIL & GAS CORP., THE	Amarillo, Tex.	Dan P. Long
SHELL OIL CO., INC.	New York, N. Y.	W. F. Court
SHELL PIPE LINE CORP.	Houston, Tex.	H. H. Anderson
SINCLAIR REFINING COMPANY, PRODUCTS PIPE LINE	Columbus, Ohio	W. W. Baker
SIOUX CITY GAS & ELECTRIC COMPANY	Sioux City, Iowa	W. J. Dougherty
SKELLY OIL COMPANY	Tulsa, Okla.	Rex L. Smith
SLINE COMPANY, INC.	Houston, Tex.	Louis L. Sline
SMITH, A. O., CORP.	Milwaukee, Wis.	W. E. Crawford
SMITH CONTRACTING CORPORATION	Fort Worth, Tex.	O. R. Smith
SOCONY-VACUUM OIL COMPANY, INC.	New York, N. Y.	S. Kleinheksel
SOCONY-VACUUM OIL COMPANY, INC., White Eagle Div.	Wichita, Kan.	Harry K. Phipps
SOHIO PIPE LINE COMPANY	Cleveland, Ohio	C. E. Spahr
SOLVENTS & PLASTICS COMPANY	St. Louis, Mo.	Wm. T. Deacon
SOUTHEASTERN PIPE LINE COMPANY	Atlanta, Ga.	B. W. Winters
SOUTHERN ALKALI CORP.	Corpus Christi, Tex.	John R. Polhamus
SOUTHERN BELL TEL. & TEL. COMPANY	Atlanta, Ga.	W. C. White
SOUTHERN COUNTIES GAS CO. OF CALIFORNIA	Los Angeles, Calif.	N. K. Senatoroff
SOUTHERN MINERALS CORP.	Corpus Christi, Tex.	F. P. Peterson, Jr.
SOUTHERN NATURAL GAS COMPANY	Birmingham, Ala.	J. W. Yeldell
SOUTHERN PACIFIC CO.	San Francisco, Calif.	E. E. Mayo
SOUTHERN UNION GAS COMPANY	Dallas, Tex.	J. C. Reid
SOUTHLAND PAPER MILLS, INC.	Lufkin, Tex.	A. E. Drew
SOUTHWESTERN GAS & ELECTRIC COMPANY	Shreveport, La.	Frank M. Wilkes
SPENCER CHEMICAL COMPANY	Pittsburgh, Kan.	Ralph D. Miller
STANDARD OIL COMPANY OF CALIFORNIA	San Francisco, Calif.	J. M. Evans
STANDARD OIL COMPANY OF INDIANA, Pipe Line Department	Chicago, Ill.	H. E. Fisher
STANDARD OIL DEVELOPMENT COMPANY, Esso Engineering Department	Elizabeth, N. J.	F. C. Fyke
STANOLIND OIL & GAS COMPANY	Tulsa, Okla.	J. B. Clark
STANOLIND PIPE LINE COMPANY	Tulsa, Okla.	J. B. Harshman
STEARNS, D. E.	Shreveport, La.	D. E. Stearns
ST. LOUIS-SAN FRANCISCO RAILWAY CO.	St. Louis, Mo.	H. B. Barry
STRATTON PIPE LINE CORP.	Corpus Christi, Tex.	K. C. Cribley
SUN OIL COMPANY	Philadelphia, Pa.	J. M. Pearson
TENNESSEE GAS TRANSMISSION CO.	Houston, Tex.	Charles Coates
TEXAS EASTERN TRANSMISSION CORP.	Shreveport, La.	Pat H. Miller
TEXAS ELECTRIC SERVICE COMPANY	Ft. Worth, Tex.	P. M. Cordell
TEXAS-EMPIRE PIPE LINE COMPANY, THE	Tulsa, Okla.	F. A. Stivers
TEXAS GULF SULPHUR COMPANY	Newgulf, Tex. (Wharton Co.)	H. E. Treichler
TEXAS-NEW MEXICO PIPE LINE COMPANY	Houston, Tex.	E. R. Osburn
TEXAS PIPE LINE COMPANY, THE	Houston, Tex.	L. F. Scherer
TEXAS PUBLIC SERVICE COMPANY	Galveston, Tex.	P. E. Nicholls
TIDE WATER ASSOCIATED OIL COMPANY	Houston, Tex.	Wm. H. Vaughan
TRANS-ARABIAN PIPE LINE COMPANY	San Francisco, Calif.	J. L. Culbertson
TRANSIT & STORAGE COMPANY, Ohio-Michigan Pipe Line Div.	Port Huron, Mich.	Luis Garcia
UNION CARBIDE & CARBON CORP.	New York, N. Y.	Geo. A. Sands
UNION OIL COMPANY OF CALIFORNIA	Los Angeles, Calif.	Vance N. Jenkins
UNION PACIFIC RAILROAD COMPANY	Los Angeles, Calif.	Wm. Reinhardt
UNION PRODUCING COMPANY	Shreveport, La.	H. P. Bennett
UNITED CHROMIUM, INC.	New York, N. Y.	R. O. Loengard
UNITED GAS CORP.	Houston, Tex.	J. C. Flanagan
UNITED GAS PIPE LINE COMPANY	Shreveport, La.	M. A. Abernathy
UNITED IRON WORKS	Oakland, Calif.	Carlo Bartolero
U. S. PIPE & FOUNDRY COMPANY	Burlington, N. J.	A. E. Schuh
UNIVERSAL OIL PRODUCTS COMPANY	Chicago, Ill.	Eugene M. Matson
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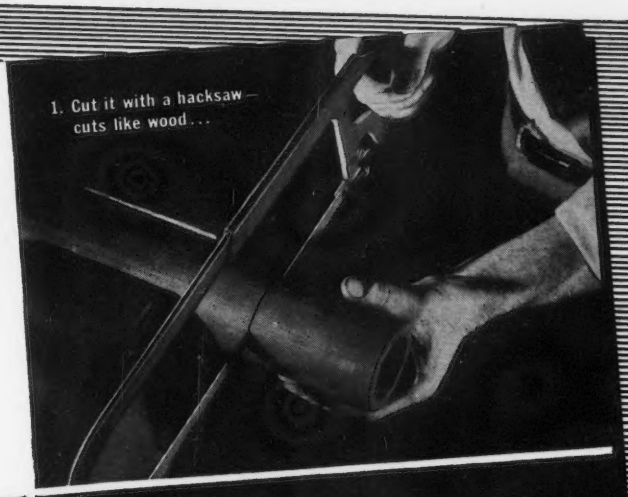

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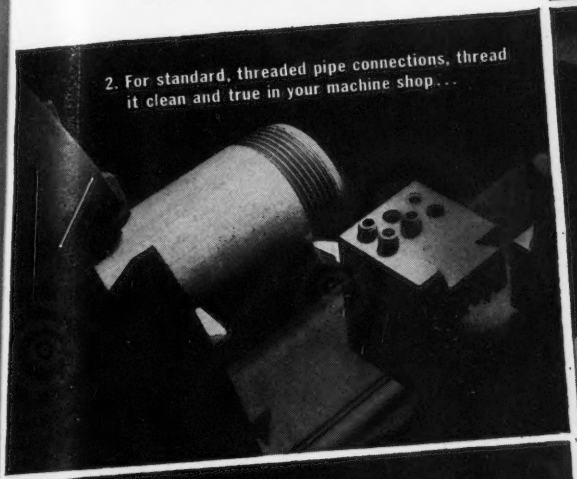

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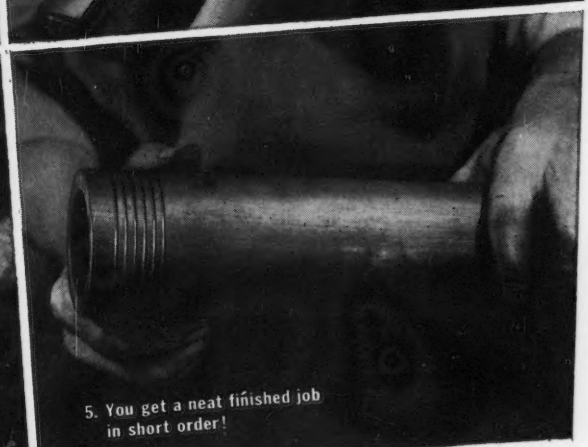

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